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Municipal Wastewater Lagoon Study
Volume 1

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16. ABSTRACT

This report presents the results of the Municipal Wastewater Lagoon Study performed by the USEPA in reponse to Section 3018 of RCRA and Sec. 246 of the Hazaroud and Solid Waste amendments of 1984. The objectives are to determine:

1. number and size of municipal lagoons
2. types and quantities of waste contained in such lagoons
3. the extent to which such waste has been or may be released from such lagoons and contaminates ground water; and
4. available alternatives for preventing or controlling such releases.

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George Denning	WH-550
Tom O'Farrell	WH-551
Ron Hoffer	WH-550G
Dove Weitman	LE-132S
James Pittman	WH-565E
Jim Basilico	RD-681
Ron Benioff	PM-220
John Gerba	A-104
Doug Newman	WH-556
Jim Patrick	Region IV
Chuck Pycha	Region V
Mike Turvey	Region VII
Jack Hofbunr	Region VIII

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EXECUTIVE SUMMARY

STUDY AUTHORITY AND OBJECTIVES

This report presents the results of the Municipal Wastewater Lagoon Study performed by the U.S. Environmental Protection Agency (EPA) in response to Section 3018 (c) of the Resource Conservation and Recovery Act (added by Section 246 of the Hazardous and Solid Waste Amendments of 1984). The objectives for the study are to determine:

(1) the number and size of municipal lagoons;
(2) the types and quantities of waste contained in such lagoons;
(3) the extent to which such waste has been or may be released from such lagoons and contaminates ground water; and
(4) available alternatives for preventing or controlling such releases.

STUDY APPROACH

- The number and size of municipal lagoons were determined by compiling a national municipal lagoon inventory from EPA's 1984 Needs Survey data base.
  - The inventory contains the following information:

    (1) lagoon locations;
    (2) number of lagoons nationwide and by State and size distribution by design flow; and
    (3) identification of relative domestic and industrial flow contributions to each lagoon.

- A literature search was conducted to compile information on alternatives for preventing or controlling ground-water contamination from lagoons.

- A review of current lagoon design practices and State regulatory requirements was conducted.
  - The report includes a compilation of State standards and criteria concerning design, construction, and ground-water monitoring.

- A limited lagoon sampling program was undertaken to assess the types and quantities of wastes contained in municipal wastewater lagoons.
  - Twenty-one lagoons were sampled: Nine with domestic waste only and 12 with both domestic and industrial waste.
  - Sampling points were influent, mid-depth in the pond, accumulated sludge at pond bottom and effluent.
  - Samples were analyzed for 126 priority pollutants and other selected pollutants.

o The ground-water quality impacts of municipal lagoons were determined using lagoon sampling data and computer modelling of ground-water quality.

  - Seven pollutants (including six priority pollutants) were selected for computer modelling. The EPACMS model was used in this study. EPACMS is a two-dimensional composite numerical/analytical solution model designed to evaluate the migration of dissolved pollutants from a surface impoundment to points of interest in an underlying aquifer. Using generalized regional hydrogeologic characteristics the model calculates the maximum allowable pollutant concentration in the lagoon seepage based upon a human health based threshold at an exposure point downgradient from the lagoon. The calculated maximum allowable pollutant concentrations are compared to the measured pollutant concentrations in the lagoon samples.

  - Human health-based thresholds used as target exposure point concentrations were selected from two sources: (1) Maximum Contaminant Levels (MCLs) as promulgated by EPA under the Safe Drinking Water Act; and (2) for those compounds without MCLs the risk specific dose (RSD) based concentrations for the 10^{-6} incremental cancer risk. MCLs represent currently acceptable concentrations of pollutants in drinking water deemed to be health protective by the Agency. MCLs reflect cost and technical feasibility of control measures as well as health effects of the pollutants.

LIMITATIONS AND ASSUMPTIONS

o Limitations of the study approach include generalization of regional hydrogeologic characteristics, limited wastewater characterization data, absence of reliable ground-water monitoring data, computer model limitations, the unknown relationship between pollutant concentrations in the lagoon effluent and those in lagoon seepage, and the lack of data on degradation of pollutants in the aerated soil zone and in ground water.

  - Assumptions for all computer model input data were conservative. Predicted pollutant concentrations in ground water are probably higher than actually exist.

  - All computer simulations use generalized hydrogeologic data and limited data on concentrations of pollutants found in lagoons, without actual ground-water monitoring data for verification.

  - The results and conclusions of this study should not be applied to sewage sludge that is placed in sludge-only landfills (monofills) or that is land applied. Sewage sludge that is used or disposed in this manner is a distinctly different material than material that accumulates in a wastewater treatment lagoon. Site characteristics may also differ significantly between sludge monofills and lagoons. EPA will be regulating use and disposal of sewage sludge including monofilling under Section 405(d) of the Clean Water Act. Proposed regulations for public comment will be issued in early 1988. In subsequent rulemaking, the Agency may regulate sludge contained in municipal wastewater lagoons under Section 405(d) of the Clean Water Act.

SUMMARY OF FINDINGS

- There are 5,500 municipal wastewater treatment lagoons nationwide; most are very small and handle only domestic wastes.
    - 50 percent of lagoons treat flows less than 0.1 million gallons per day (MGD)
    - 90 percent of lagoons treat flows less than 0.5 mgd.
    - Less than 8 percent of lagoons receive significant industrial discharges.
    - Lagoons are used in all States except one, however one-third are in the 12 midwestern States (see figure ES-1).
    - Lagoons which treat a combination of domestic and industrial wastes are used in a number of States, however, the greatest concentration of such lagoons occur in the midwest (see figure ES-2).
- States have widely varying requirements for municipal wastewater treatment lagoons.
    - 18 States require ground-water monitoring wells for lagoons under certain specific circumstances or based upon a case-by-case evaluation of their need. Five additional States require monitoring under specific conditions (e.g., unlined lagoon). Few municipal lagoons have monitoring wells and those few wells are not properly located to detect ground-water contamination. When required, monitoring is usually conducted for conventional (i.e., non-priority) pollutants only.
    - 12 States require linings for all lagoons, 18 States require linings as necessary to meet either State permeability criteria or case-by-case demonstrations of need, 19 States have no specific lining requirements, and one State does not allow lagoons. Most municipal lagoons have linings of various types primarily formed from imported clay or compacted clayey or other soils existing at the site.
- There were approximately 3 times as many priority pollutants in municipal lagoons that treat industrial wastes as compared to those that treat domestic waste only.
    - 94 priority pollutants at concentrations up to 1,000 ppb were found in domestic/industrial lagoons
    - 35 priority pollutants at concentrations up to 280 ppb were found in domestic lagoons.

- Seepage from domestic/industrial lagoons is more likely to contaminate nearby aquifers than seepage from similarly constructed and located domestic only lagoons.

  - Lagoons receiving only domestic wastes are unlikely to sufficiently affect ground water to exceed present MCL's at exposure points. However domestic/industrial lagoons may cause certain MCL's to be exceeded.

  - Domestic and domestic/industrial waste lagoons may sufficiently affect ground water to exceed RSD-based concentrations.

- There are effective remedial measures for existing lagoons and precautionary measures for new lagoons to prevent and control ground-water contamination from municipal wastewater treatment lagoons.

  - EPA's Office of Research and Development has performed numerous studies which document methods for preventing or controlling ground-water contamination from municipal wastewater lagoons.

  - Remedial measures for existing lagoons include:

    - Clean up contaminated ground water and soils, if necessary
    - Repair or replace liners
    - Install monitoring wells
    - Improve sampling and chemical analyses to include toxic pollutants
    - Improve State requirements for lagoon sampling and monitoring
    - Review pretreatment requirements and implement changes if needed

  - Measures for new lagoons include:

    - Site selection criteria
    - Improve liners
    - Proper monitoring well installation
    - State requirements for lagoon sampling and monitoring
    - Improve construction inspection procedures
    - Consider pretreatment requirements as appropriate.

CONCLUSIONS

- The potential for ground-water contamination from municipal wastewater lagoons is low. It appears, however, that some lagoons with industrial discharges may be potential sources of ground-water contamination.

- Human health risks associated with ground-water contamination from domestic lagoons are generally low and within an acceptable range. Lagoons with significant industrial discharges pose a potential risk to human health.

- Existing State standards for lagoon design and construction and for ground-water monitoring vary widely and some may be inadequate for protection of ground water where lagoons receive significant industrial discharges. States should review their standards and monitoring requirements for lagoons that receive significant industrial waste and which are located in highly vulnerable hydrogeologic settings or in proximity to drinking water wells.

FIGURE ES-1

LOCATION OF MUNICIPAL LAGOONS BY STATE

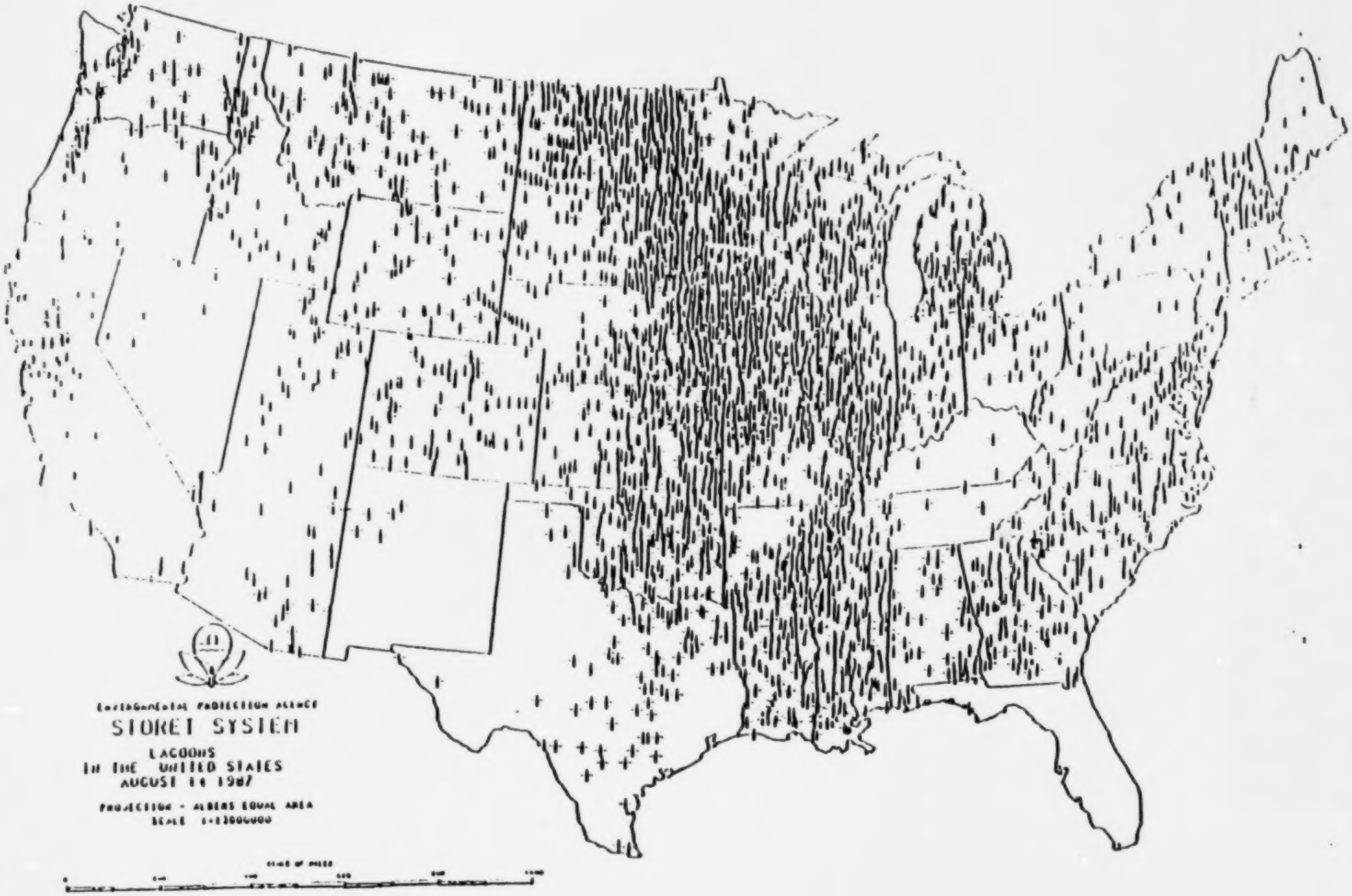
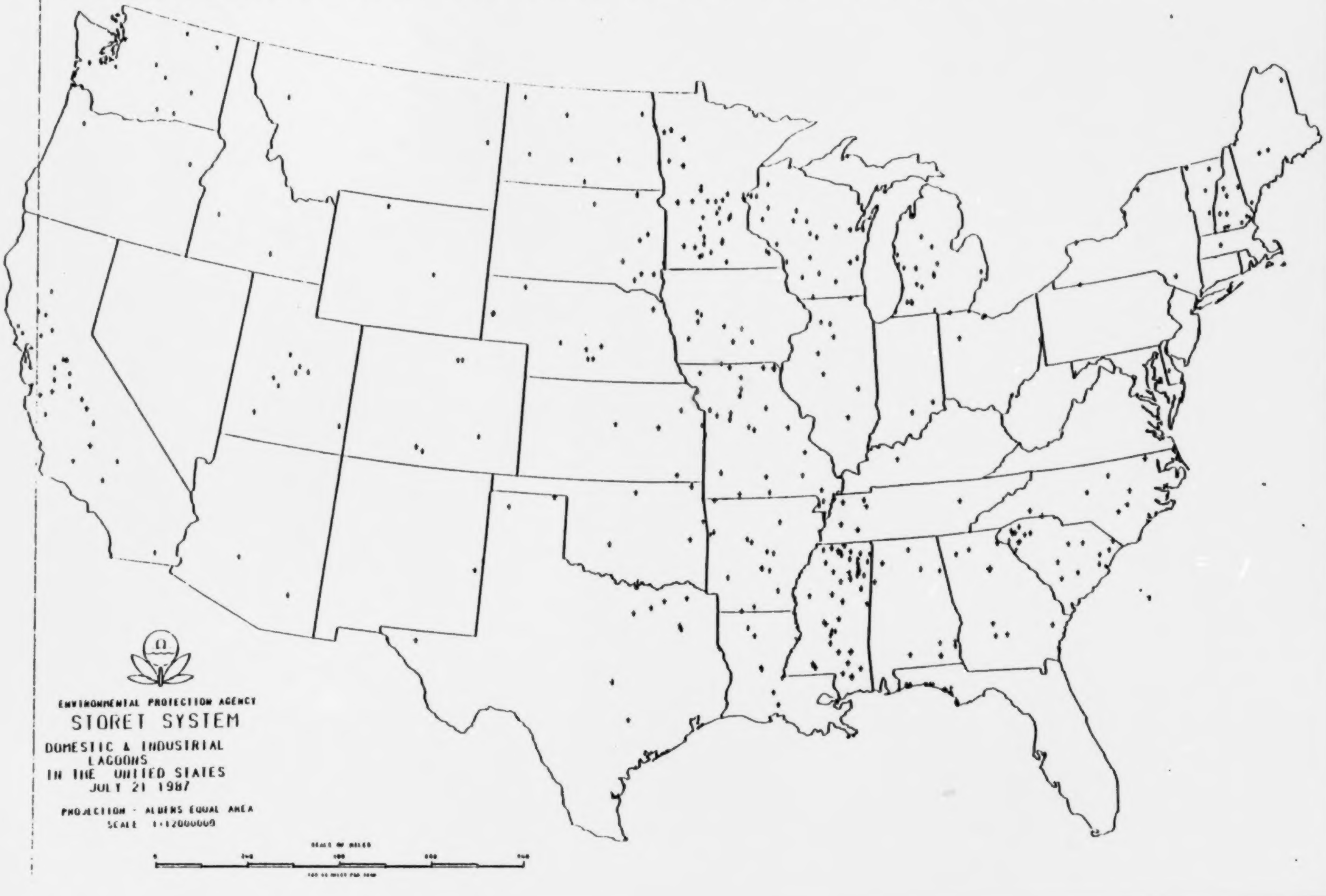


FIGURE ES-2

LOCATION OF DOMESTIC/INDUSTRIAL LAGOONS BY STATE



CHAPTER 1

INTRODUCTION

Section 246 of the 1984 Amendments to the Resource Conservation and Recovery Act (RCRA) adds section 3018(c) which requires that the U.S. Environmental Protection Agency (EPA) conduct a study and submit a report to Congress concerning wastewater treatment lagoons at publicly owned treatment works and their effect on ground-water quality. Wastewater treatment lagoons are frequently used by small communities to provide a low-cost method for treating their wastewater. Based on 1984 Needs Survey data, 5,476 lagoons exist in the United States. Specifically, Section 246 asks for:

- An inventory of municipal lagoons (number and size);
- The types and quantities of wastes present in municipal lagoons;
- The extent to which wastes from lagoons may contaminate ground water; and
- Available alternatives for preventing or controlling such contamination.

EPA initiated work on the study in early 1985, shortly after the passage of the RCRA Amendments. A number of EPA offices and contractors were utilized to assist in the development of the study approach and in the performance of the study. This report presents the results of this three-year effort.

Chapter 2 briefly describes the methodology and limitations of the approach. Chapter 3 identifies the location of municipal lagoons and describes their waste characteristics. An assessment of potential ground-water contamination from lagoons is presented in Chapter 4 followed by analysis of the potential health risks in Chapter 5. Finally Chapter 6 describes available alternatives to prevent such ground-water contamination. These Chapters give the reader a solid overview of the issues involved including summaries of the important points discussed. Most of the data summaries, computer printouts, and detailed methodology are presented in the appendices for those who desire additional information.

CHAPTER 2

METHODOLOGY AND LIMITATIONS

2.1 APPROACH

The approach developed to meet each of the specific objectives of the study is briefly outlined in the following sections.

2.1.1 Lagoon Inventory and Waste Characterization

The inventory of municipal lagoons was based on the 1984 Needs Survey data developed by the EPA. Needs Survey data were reviewed and analyzed to identify the size, location, and lagoon type of the 5,476 lagoons in the inventory.

A limited sampling program identified types and amounts of EPA's 126 priority toxic pollutants, plus a few additional selected pollutants, in the wastewaters of some lagoons and provided data used for the national assessment of potential ground-water contamination. Twenty-three lagoon systems nationwide were selected for sampling and characterization. The first ten lagoons selected each have nearby ground-water monitoring wells. The second group of 13 lagoons includes those with a significant contribution of wastes from industrial sources, variations in their sizes, and diversity in their geographic locations. Data from two of these 13 lagoons were obtained from independent sources outside this study.

Samples taken from each lagoon were analyzed for priority toxic pollutants and for selected non-conventional pollutants and pollutant parameters (barium, total phenols, total organic carbon, ammonia nitrogen, oxidized nitrogen, and chloride). The evaluation of laboratory analytical data from the lagoon samples identified the concentrations and frequency of occurrence of specific pollutants.

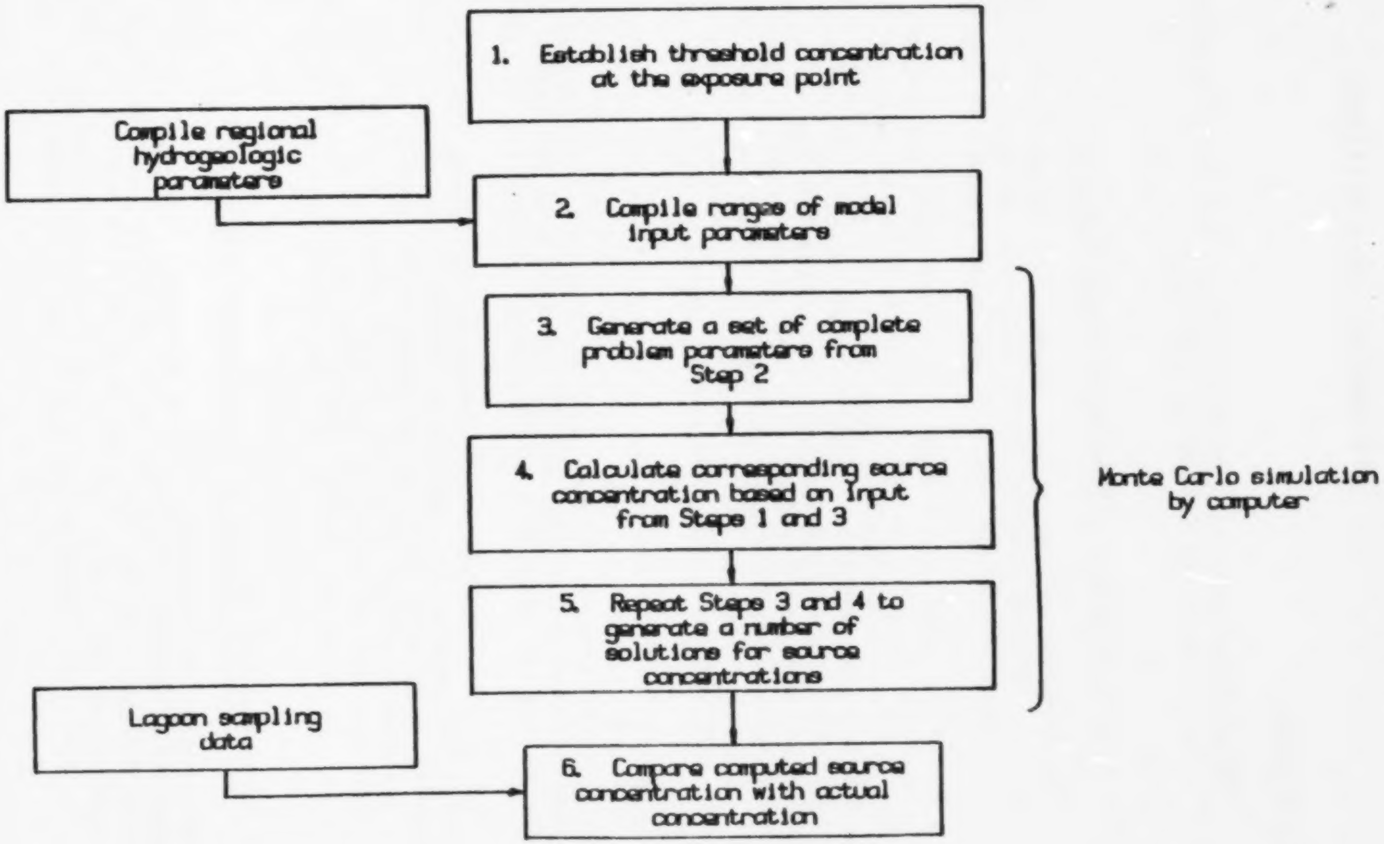
The sampling program was designed to facilitate the assessment of ground-water contamination caused by municipal wastewater lagoons. Lagoons which receive industrial wastewater may also be significant sources of air pollutant emissions. Since assessment of air emissions was not a goal of this study the sampling was not conducted in a way to determine air emissions. Thus, data presented in this report should not be used to assess air emissions from municipal wastewater lagoons.

2.1.2 Assessment of Potential Ground-water Contamination

The impact of pollutants from municipal lagoons could be most effectively assessed by direct field monitoring at selected lagoons. Such an approach was not feasible, however, due to the absence of existing monitoring data, the great variety of lagoon sizes and types, the site-specific hydrogeologic settings, and the high cost of full field monitoring activities. Instead, the assessment employed a

FIGURE 2-1

NATIONAL ASSESSMENT OF POTENTIAL
GROUND-WATER CONTAMINATION
MUNICIPAL LAGOON STUDY


1. Establish threshold concentration at the exposure point
Compile regional hydrogeologic parameters
2. Compile ranges of model input parameters
3. Generate a set of complete problem parameters from Step 2
4. Calculate corresponding source concentration based on Input from Steps 1 and 3
5. Repeat Steps 3 and 4 to generate a number of solutions for source concentrations
Monte Carlo simulation by computer
Lagoon sampling data
6. Compare computed source concentration with actual concentration

combination of limited field monitoring and computer simulation. This approach, shown by Figure 2-1, depends upon the use of an effective pollutant migration simulation model and the development of realistic lagoon scenarios for input to the model.

Initially, the assessment focused on the selection of a computer model. Several models were investigated and two were selected for testing by simulation runs. One of these two models, the sophisticated Sandia Waste Isolation and Flow Transport (SWIFT) model, requires site-specific data including ground-water monitoring data from a large number of lagoons representing specific hydrogeologic settings. It was rejected because of the small number of lagoons sampled and the lack of reliable data from the few ground-water monitoring wells for calibration or verification.

The selected model, EPACMS, allows the user to choose a human health-based threshold at an exposure point (ground-water monitoring well) downgradient from a municipal lagoon and back-calculate the corresponding maximum allowable source concentration in the lagoon seepage. Since site-specific situations are unavailable, the hydrogeologic and geochemical parameters used in the model calculations are generated from the range of values known to exist for certain hydrogeologic regions. The EPACMS program then generates repeated hypothetical input data and back-calculates corresponding source concentrations. This approach fits the municipal lagoon study because only limited site-specific data were available for the generation of the national assessment.

A data base of realistic lagoon scenarios was generated for the assessment. Hydrogeologic data were compiled using a methodology to systematically evaluate the relative vulnerability of ground water associated with hydrogeologic settings located throughout the United States (previously developed by cooperative agreement between the National Water Well Association and the USEPA's Robert S. Kerr Environmental Research Laboratory). This methodology, designated by the acronym DRASTIC, is a standardized system for the evaluation of ground-water contamination potential based on available geologic data (1). DRASTIC divides the entire nation into 15 ground-water regions and subdivides each region into typical hydrogeologic settings. The vulnerability of each hydrogeologic setting to ground-water contamination is indexed by key factors controlling the migration of pollutants from the land surface to the ground-water table. Without site-specific data, selected DRASTIC parameters are necessarily the key inputs for the lagoon scenario data base. In addition, the lagoons within the national inventory were located within the appropriate DRASTIC subdivisions. These subdivisions (and lagoons) were then recombined into "hydrogeologic categories" to form the basis of the national assessment. Results of the assessment could then, if desired, be referenced to the relative numbers of lagoons within each hydrogeologic category.

2.1.3 Selection of Target Exposure Point Concentrations

Before conducting the computer modelling and subsequent analysis, human health-based thresholds were determined for use as target exposure point concentrations. Two sources were used to identify these thresholds; (1) Maximum Contaminant Levels (MCLs) and Maximum Contaminant Level Goals (MCLGs) as promulgated by EPA; and (2) for those compounds without MCLs or MCLGs, existing information on acceptable chronic exposure (noncarcinogens) and potential incremental carcinogenic risk (carcinogens). These sources are discussed below.

Under the authority of the Safe Drinking Water Act (SDWA), the EPA regulates drinking water contaminants that may cause adverse health effects in humans and are known or anticipated to occur in drinking water. Drinking water regulations consist of two components. The first component involves the establishment of a nonenforceable health goal called a maximum contaminant level goal (MCLG). The MCLG is set at a level at which no known or anticipated adverse health effects will occur and which allows an adequate margin of safety. If the contaminant is classified as a known or probable human carcinogen, the MCLG is set at zero. For noncarcinogens the MCLG is derived from the Reference Dose (RfD) for exposure ingestion (formerly called an acceptable daily intake). The RfD represents an estimate of a daily exposure that would not increase the risk of an adverse health effect. The RfD is adjusted for a 70-kilogram adult consuming 2 liters of water daily. The MCLG is derived from this value by multiplying by the known or estimated percentage exposure from a drinking water source.

The second component of the drinking water regulations is called the Maximum Contaminant Level (MCLs). The MCL is an enforceable standard and is set as close to the MCLG as is technologically and economically feasible. For noncarcinogens, the MCL most often will equal the MCLG. For carcinogens, the MCL is set within the 10^{-4} to 10^{-7} excess cancer risk range for that contaminant. EPA proposes and promulgates both MCLs and MCLGs concurrently. As of July 1987, approximately 30 contaminants are regulated under the SDWA. A total of 83 contaminants are to be regulated by June 19, 1989.

For contaminants without MCLs or MCLGs, human health-based thresholds used in this study were estimated on the basis of RfDs (noncarcinogens) and an excess lifetime cancer risk of 10^{-6} (Group A and B carcinogens) or 10^{-5} (Group C carcinogens), based on the Risk Specific Dose (RSD) for ingestion as developed from established carcinogenic potency factors. As for MCLs and MCLGs, the RSDs and RfDs are adjusted for a 70-kilogram adult consuming 2 liters of water daily. Unlike the MCLs/MCLGs, the resulting concentrations were not adjusted for the expected percentage exposure via the drinking water route. These alternate human health-based thresholds were developed for the pollutants found in the lagoon characterization program, and used for the selection of specific chemicals for modelling.

2.1.4 Preventive and Corrective Measures

Information on corrective and preventive measures for controlling ground-water contamination from municipal lagoons was gathered and compiled for review. Information sources included a computerized literature search, EPA publications and personnel, commercial vendors and State regulatory agencies. Available corrective and preventive measures were grouped into three major areas: (1) design/construction techniques for new lagoons; (2) retrofitting techniques for existing lagoons; and (3) cleanup activities following discovery of soil/ground-water contamination from existing lagoons. Specific technologies and regulatory requirements in each area are described in this report and references are identified for additional information. EPA's Office of Research and Development has performed numerous studies which document methods for preventing or controlling ground-water contamination from municipal wastewater lagoons.

2.2 LIMITATIONS OF APPROACH

The approach for this study was developed based on the maximum utilization of the available information and resources. The assessment presented in this report provides a general indication of the concentrations and types of pollutants found in municipal lagoons and an estimate of the potential, on a national basis, for ground-water contamination due to pollutant releases through seepage from the lagoons. The limitations of the data available and the study approach itself prevent identification of any individual lagoons as posing a threat to ground-water resources. Furthermore, because of the data limitations, several conservative assumptions are made which very likely overstate the threat posed to ground water. Nonetheless, the methodology used in this national assessment defines those sets of circumstances that create the greatest potential for ground-water contamination from municipal lagoons. The information in the report, although generalized, is useful in the review or development of regulations and guidance for the management, planning, design and construction of municipal lagoons and for planning more detailed studies of lagoons and their impacts on ground-water resources. The findings and conclusions of the report and the interpretation of the study results must recognize a number of specific limitations inherent in the approach developed for the study. These limitations, briefly discussed in the following sections, and their likely impact on the results of the study should be thoroughly understood before drawing conclusions from the study results.

2.2.1 Diversity of Lagoon Scenarios

Results of the Needs Survey and limited sampling program demonstrate the large diversity of lagoon types, settings, locations, and wastewater treated. This diversity, the large number of lagoons identified and lack of existing ground-water monitoring data prevent estimation of the actual number of lagoons posing a threat to ground water.

2.2.2 Data Limitations

The migration of specific pollutants to the ground water depends on site and pollutant-specific hydrogeologic and chemical parameters. The current understanding of many of these individual parameters and their interactive effects is limited; therefore, substantial verification of data is needed. Unfortunately, the amount and quality of available lagoon characterization or monitoring data are severely limited (23 lagoons with wastes characterized and without valid ground-water data compared with 5,476 lagoons nationwide). Therefore, all computer simulations use generalized hydrogeologic data and limited data on concentrations of pollutants found in lagoons, without actual ground-water monitoring data for verification. Although the computer simulation results represent the best available information at this time for a nationwide assessment, reliable lagoon and ground-water data are still needed for verification of the modelling results.

2.2.3 Use of Computer Modelling

Both the data inputs and the capabilities of the computer model limit the validity of the modelling results. This study attempts to match the data limitations with the sophistication of the model. EPACMS, although designed for a generalized approach, allows the incorporation of chemical reactions and the biological decay of specific pollutants. Nonetheless, physical constants for some of these reactions are yet unknown. In addition, the model omits chemical transformations known to occur for specific pollutants investigated in this study. Therefore, the study results are conservative; actual concentrations of pollutants in the ground water may be significantly lower than those estimated.

2.2.4 Impact of Lagoon Seepage

Presently, the technical basis is limited for determining pollutant migration from lagoon seepage. The rate of seepage and migration of the pollutants depends on the nature of the lagoon bottom, underlying hydrogeology, and the specific pollutants. Actual data for comparison of pollutant concentrations in lagoons with concentrations in seepage immediately beneath a lagoon do not now exist. Therefore, seepage concentrations were likely overestimated for the study.

2.2.5 Summary

A number of limitations inherent in the study approach must be recognized and incorporated into the interpretation of data. These include the generalization of regional hydrogeologic characteristics, the limited characterization/monitoring data, the diversity of lagoon scenarios, computer limitations, and the unknown impact of lagoon seepage. Although the results of the study represent the best available information at this time, actual site-specific data are needed for verification of these results. As conservative assumptions have been made throughout the study, the actual concentrations of contaminants in ground water and the resulting human health impacts may be significantly less than those indicated herein.

REFERENCES

CHAPTER 2

1. National Water Well Association (NWWA), 1985. DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings, EPA/600/2-85/018, National Technical Information Service, Springfield, VA.

CHAPTER 3

LAGOON DESIGN, INVENTORY AND CHARACTERIZATION

This chapter presents an inventory of the nation's POTW wastewater lagoons, including a review of State regulations and guidelines for their design, construction and operation, as well as a description of such lagoons' wastewater characteristics.

3.1 TYPES OF LAGOONS

Lagoons are classified by dominant type of biological reaction (1). The four principal types are:

- Facultative (aerobic-anaerobic)
- Aerated
- Aerobic
- Anaerobic

Appendix 3.1 (Table 3.1-1) summarizes design criteria and other information on the four types of lagoons.

3.1.1 Facultative Lagoons

Facultative lagoons, the most common type, treat wastewater by anaerobic fermentation in the lower layer and aerobic stabilization in the upper layer. The key treatment mechanisms comprise oxygen production by photosynthetic algae and surface reaeration. Aerobic bacteria use the oxygen to stabilize the organic material in the upper layer.

Facultative lagoons are used to treat raw municipal wastewater (usually from small communities) and also to treat primary or secondary effluent (for small or large cities). The facultative lagoon is the easiest to operate and maintain. Large land areas are required to maintain lagoon biochemical oxygen demand (BOD_5) loadings in a suitable range. The lagoon's facultative treatment capability for raw wastewater usually does not exceed secondary treatment.

3.1.2 Aerated Lagoons

In an aerated lagoon, oxygen for breakdown of pollutants is supplied mainly through mechanical or diffused air aeration rather than by photosynthesis and surface reaeration. Many aerated lagoons are modifications of overloaded facultative lagoons that require aerator installation to supply additional oxygen for proper treatment performance. BOD_5 and suspended solids (SS) removal in facultative lagoons can be increased with sufficient aeration and mixing. Aerated lagoons require less land than facultative lagoons.

3.1.3 Aerobic Lagoons

Aerobic lagoons, much shallower than either facultative or aerated lagoons, maintain dissolved oxygen throughout their entire depth. Oxygen, provided by photosynthesis and surface reaeration, is used by bacteria to stabilize the pollutants. Mixing is often provided to expose all algae to sunlight and to prevent anaerobic conditions at the bottom of the lagoon. Use of aerobic lagoons is limited to warm, sunny climates where a high degree of BOD_5 removal is desired but land area is limited. Because of shallow lagoon depths, the bottoms of aerobic lagoons must be paved or covered to prevent weed growth.

3.1.4 Anaerobic Lagoons

Anaerobic lagoons receive such a heavy organic loading that formation of an aerobic zone is prevented. The principal biological reactions comprise acid formation and methane fermentation. Use of anaerobic lagoons is limited principally to treatment of strong industrial and agricultural wastes, or to pretreatment where an industry contributes wastewater to a municipal system.

3.2 REGULATIONS AND GUIDELINES RELATED TO LAGOON DESIGN, CONSTRUCTION AND OPERATION

This section reviews State regulations and guidelines related to the design, construction and operation of municipal wastewater lagoons with emphasis on those practices pertaining to ground-water protection.

Originally, design criteria for wastewater lagoons were relatively simple and were directed toward retention times, depth, number of ponds, and loadings. In a state-of-the-art review of waste treatment lagoons in 1971, the Missouri Basin Engineering Health Council stated that most health departments have more detailed design criteria (2). Another publication, "Recommended Standards for Sewage Works, Great Lakes-Upper Mississippi River Board of State Sanitary Engineers," presents typical design criteria that are employed by engineers in the design of wastewater lagoons (3). EPA's Design Manual for Municipal Wastewater Stabilization Ponds (1983) (4) describes technological advances and presents information for engineers and municipal officials on lagoon planning, design, construction and operation.

A survey of State requirements for ground-water protection, conducted for the U.S. Army Cold Regions Research and Engineering Laboratory in the late 1970s (5), was updated as part of this study. Appendix 3.1 (Table 3.1-2) summarizes requirements concerning lining, seepage or permeability limitations, and ground-water monitoring. Of the 50 States, 12 require liners, one (Rhode Island) does not allow lagoons, 18 evaluate the need for lining lagoons on a case-by-case basis, and 19 have no specific lining requirements. Ground-water conditions affect decisions on providing liners and monitoring programs. Appendix 3.1 (Table 3.1-3) presents expected seepage rates for selected liner materials.

Seepage limitations vary substantially among States. Some States have no requirements and others specify stringent permeability limitations, as low as 10^{-6} to 10^{-7} centimeters per second.

Appendix 3.1 (Table 3.1-4) summarizes the general ground-water monitoring requirements for each of the 50 States and also presents specific monitoring information for each State. In all, 18 States have some form of monitoring requirements that can be applied on a case-by-case basis or that are required as standard practice. (Five additional States have set monitoring requirements for specific situations such as unlined lagoons). The minimum number of wells required for each site, the sampling frequency, and the pollutants to be monitored vary widely among the States.

In addition to requirements for ground-water monitoring wells, States have established standards for the location of water supply wells with respect to potential sources of pollution such as municipal lagoons. These requirements vary widely and are dependent on a number of variables (e.g., the establishment of whether the well is a public or private water supply). Wells installed prior to siting regulations are often "grandfathered" and remain operative until closed on an individual basis.

As can be seen from the above discussion, State requirements for the design, construction and operation of municipal lagoons vary widely. In addition to the actual regulations and guidelines, it is likely that enforcement activities are similarly varied.

3.3 INVENTORY OF LAGOONS

The source of data for the USEPA lagoon inventory was the 1984 Needs Survey data base (6). The inventory comprises 5,476 municipal lagoons (Appendix 3.2) of which 5,043 contain domestic wastes (domestic lagoons) from residential, commercial and institutional sources; and 433 contain wastes from industrial as well as domestic sources (domestic/industrial lagoons). Lagoons treat waste from about 13 million (8 percent) of the about 170 million persons nationwide served by municipal wastewater treatment systems. Figure 3-1 shows the location of the nation's 5,476 municipal lagoons, while Figure 3-2 shows the 433 domestic/industrial lagoons.

3.3.1 Domestic Lagoons

Domestic lagoons serve about 10 million persons or six percent of those served by municipal treatment systems. Of the 5,043 domestic lagoons in the nation, approximately 60 percent (3015 lagoons) are designed for flows of 0.1 mgd or less and 95 percent (4,791 lagoons) are designed for flows of less than or equal to 0.6 mgd. The distribution of design flow rates for the total population of domestic lagoons is presented in Table 3-1. The average flow rate for the entire domestic lagoon population is 0.19 mgd; only two lagoons are designed for flows exceeding 10 mgd. To place this information in perspective, using a per capital generation rate of 100 gallons per day, a flow rate of 0.1 mgd corresponds to a population of 1,000, while 0.2 mgd corresponds to 2,000 people. Therefore, most lagoons serve small municipalities.

FIGURE 3-1

LOCATION OF MUNICIPAL LAGOONS BY STATE

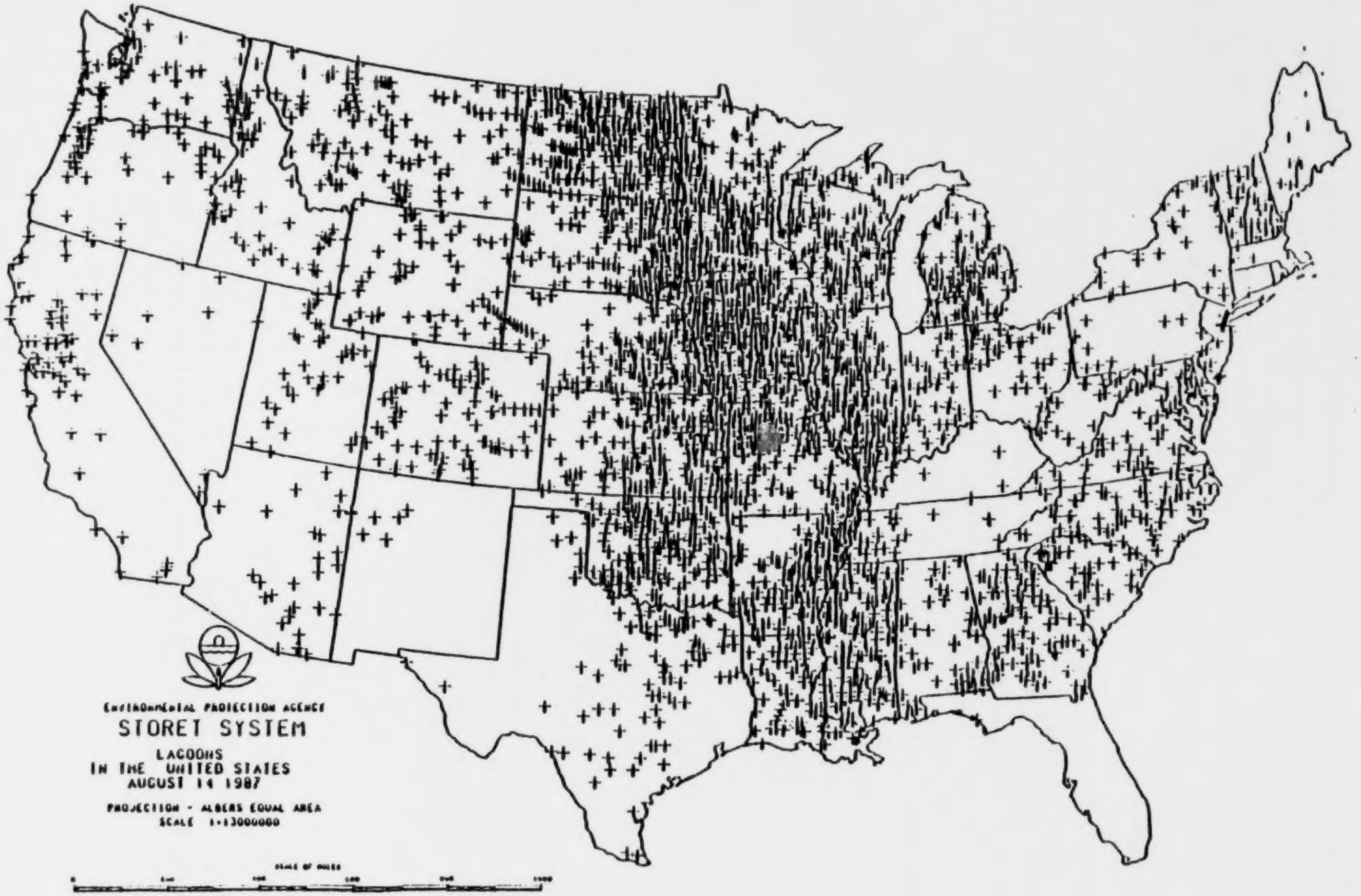
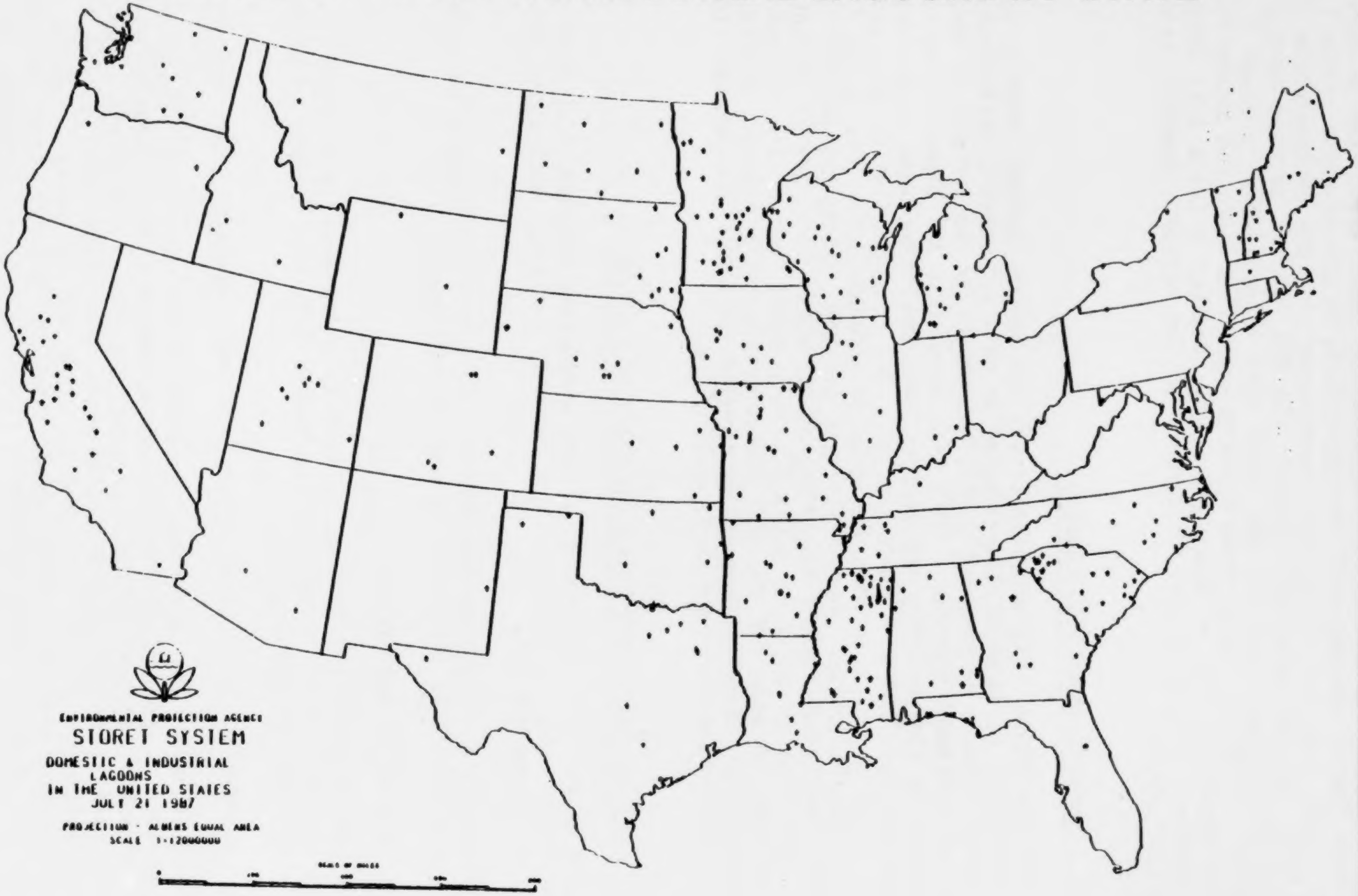


FIGURE 3-2

LOCATION OF DOMESTIC/INDUSTRIAL LAGOONS BY STATE


ENVIRONMENTAL PROTECTION AGENCY
STORET SYSTEM
DOMESTIC & INDUSTRIAL LAGOONS IN THE UNITED STATES
JULY 21 1987
PROJECTION - ALBERS EQUAL AREA
SCALE 1:12000000
SCALE OF MILES
0

The above flow information, converted to lagoon areas, can be used to estimate the mass flux of contaminants into the underlying ground-water system (See Appendix 3.3). This mass flux (gram/year) depends on: (1) the concentration of pollutants in lagoon seepage (gram/cubic meter); (2) the rate of seepage through the lagoon bottom (meter/year); and (3) the total area through which seepage occurs (square meters). Estimated lagoon areas based on known flow rates and assumptions regarding lagoon dimensions and residence times are presented in Table 3-1, which shows that the expected size of almost 90 percent of the nation's domestic lagoons is less than 15.5 acres.

3.3.2 Domestic/Industrial Lagoons

In the nation, 433 domestic/industrial lagoon systems receive various types and quantities of industrial wastewater as well as domestic wastewater. Domestic/industrial lagoons serve about 3 million persons or two percent of those served by municipal treatment systems. Table 3-2 summarizes the domestic/industrial lagoon population by flow category and percent industrial flow based on the data presented in Appendix 3.2. (Also included in Table 3-2 is a compilation of estimated lagoon areas, based on the conversion presented in Appendix 3.3). The design flow rate for the domestic/industrial lagoons averages 1.1 mgd. Sixty-six percent (286) of the domestic/industrial lagoons have flows of 0.5 mgd or less, and 97 percent (419) have flows less than or equal to 5.0 mgd. Only seven lagoons are designed for flows greater than 10 mgd. Of the 433 domestic/industrial lagoons, almost half (214) have industrial contributions of 20 percent or less; one-quarter (107) have an industrial content varying from 21 to 40 percent.

3.4 GENERAL WASTEWATER CHARACTERISTICS OF LAGOONS

The nature and composition of the wastewater treated in a municipal lagoon system depend upon its source(s). In general, municipal wastewater can be divided into four components (7):

- Domestic (sanitary) wastewater, including discharge from commercial and institutional facilities as well as residences;
- Industrial wastewater;
- Infiltration and inflow, defined as extraneous water entering the sewer system from the ground and stormwater from roof leaders, foundation drains and similar sources; and
- Stormwater (if storm sewers are not separate from sanitary sewers).

Traditionally, the pollutants contained in raw and treated sewage are measured using parameters such as biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), dissolved oxygen, solids, nitrogen, phosphorus and grease. Typical values of these parameters are provided in Appendix 3.4 (Table 3.4-1). The Clean Water Act Amendments of 1977 directed EPA to study and periodically update a list of toxic pollutants that have since become known as "priority toxic pollutants." The current list of 126 priority pollutants (volatile organic compounds, acid extractable organic compounds, pesticides/PCBs, base/neutral extractable compounds, metals, and miscellaneous compounds) is presented in Appendix 3.4, Table 3.4-2.

TABLE 3-1

DOMESTIC LAGOON DISTRIBUTION

Flow Category[a,b] (mgd)	Area Category[c,d] (acres)	Number of Lagoons		Percent of Total Lagoons	
		By Category	Cumu-lative	By Category	Cumu-lative
≤ 0.100	≤ 05.18	3,015	3,015	59.8	59.8
0.101 - 0.200	5.23 - 10.36	978	3,993	19.4	78.0
0.201 - 0.300	10.42 - 15.55	423	4,416	8.4	87.6
0.301 - 0.400	15.60 - 20.73	166	4,582	3.3	90.9
0.401 - 0.500	20.78 - 25.91	126	4,708	2.5	93.4
0.501 - 0.600	25.96 - 31.09	83	4,791	1.6	95.0
0.601 - 0.700	31.14 - 36.27	39	4,830	0.8	95.8
0.701 - 0.800	36 33 - 41.46	45	4,875	0.9	96.7
0.801 - 0.900	41.51 - 46.64	20	4,895	0.4	97.1
0.901 - 1.000	46.69 - 51.82	34	4,929	0.7	97.7
1.001 - 1.500	51.87 - 77.73	60	4,989	1.2	98.9
1.501 - 2.000	77.78 - 103.64	18	5,007	0.4	99.3
2.001 - 3.000	103.69 - 155.46	18	5,025	0.4	99.6
3.001 - 4.000	155.51 - 207.28	8	5,033	0.2	99.8
4.001 - 5.000	207.33 - 259.10	4	4,037	0.1	99.9
5.001 -10.000	259.15 - 518.20	4	5,041	0.1	99.9+
>10.000	> 518.20	2	5,043	<0.1	100.0

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[a] Based on present design flow.

[b] Average flow = 0.19 mgd.

[c] Based on median hydraulic residence time of 102.5 days and median depth of 6 feet.

[d] The small discontinuities between the area categories are due to the effects of rounding on the flow-to-area conversion process.

TABLE 3-2
DOMESTIC/INDUSTRIAL LAGOON DISTRIBUTION

Flow Category (mgd)[a,b]	Area Category (acres)[c,d]	Number of Lagoons		Industrial Contribution[e]	
		By Category	Percent	By Category	Number of Lagoons
≤0.100	≤5.18	85	20	0- 20	34
				21- 40	31
				41- 60	9
				61- 80	3
				81-100	8
0.101-0.500	5.23-25.91	201	45	0- 20	108
				21- 40	46
				41- 60	27
				61- 80	15
				81-100	5
0.501-1.000	25.96-51.82	65	15	0- 20	33
				21- 40	12
				41- 60	8
				61- 80	6
				81-100	6
1.001-5.000	51.87-259.10	68	16	0- 20	33
				21- 40	17
				41- 60	7
				61- 80	3
				81-100	8
5.001-10.000	259.15-518.20	7	2	0- 20	3
				21- 40	1
				41- 60	1
				61- 80	0
				81-100	2
>10.000	>518.20	7	2	0. 20	3
				21- 40	0
				41- 60	0
				61- 80	0
				81-100	4
Total	-	433	100	-	433

[a] Based on present design total flow.

[b] Average flow = 1.1 mgd.

[c] Based on median hydraulic residence time of 102.5 days and median depth of 6 feet.

[d] The small discontinuities between the area categories are due to the effects of rounding on the flow-to-area conversion process.

[e] Based on percent design industrial flow.

A 1980 study (8) identifies eight different household sources of one or more priority pollutants and the product categories associated with each source (Appendix 3.4, Table 3.4-3). A survey of production and use information for these 126 priority pollutants found that the most frequently used products containing the priority pollutants are household cleaning agents and cosmetics. These products are used on a daily basis and contain solvents and heavy metals as their main ingredients. Also high in frequency of use are deodorizers and disinfectants which contain naphthalene, phenol and chlorophenols. Products that are used and wasted less frequently (i.e., once a week at most) include pesticides, laundry products, paint products, polishes and preservatives. Appendix 3.4 (Table 3.4-4) presents priority pollutants potentially present in each of the eight household waste sources. Based on these data, 23 priority pollutants (14 organics and 9 metals) are identified as being commonly present in domestic wastewater.

Appendix 3.4 (Table 3.4-4) shows that domestic wastewater sources contribute priority pollutants to municipal lagoons. The concentrations of these pollutants, either in absolute terms or relative to the concentrations in industrial wastewater, vary depending on the time of day, week, or year (e.g., paint use increases on weekends, pesticide use in the summer). While these concentrations are usually small, they may be significant in some cases; this significance should be defined on an individual, site-by-site basis.

3.5 SAMPLING OF INDIVIDUAL LAGOONS

3.5.1 Overview of Sampling Program

The objectives of the lagoon sampling program were: (1) to identify pollutants of concern for computer modelling; and (2) to obtain data to assess ground-water contamination. The sampling program was conducted in two phases. The first phase involved 10 lagoon systems, selected because of the presence of ground-water monitoring wells. Data from the first phase were expected to provide information on ground-water contamination by lagoons. Additionally, the data were to be used to verify results of the computer modelling.

Because few lagoons have ground-water monitoring wells already installed, the selection of lagoon systems for sampling was not random, thus introducing bias into the sampling program. Additionally, conditions at some of the 10 sites were not suitable for assessing the extent of contamination due to lagoon operations. For example, one lagoon system (Laramie, WY) was designed as a percolation pond system, and "upgradient" wells at other lagoon systems were located so close to the lagoon that they would likely be influenced by lagoon seepage. Consequently, the results of the initial round of sampling were more suited to lagoon wastewater characterization than to an assessment of ground-water contamination.

Recognizing the above limitations, a second phase of sampling was conducted to gather more data. The eleven lagoon systems sampled in this phase were selected primarily on the basis of their industrial waste content and diversity of location. Data from two additional lagoon systems, located in Everett, WA and Muskegon, MI, were obtained from other sources for use in this study.

3.5.2 Lagoons Sampled

Selected facilities in the domestic and domestic/industrial lagoon categories were visited and sampled for priority pollutants (except dioxin), barium, total phenols and for selected non-conventional pollutants (total organic carbon, ammonia nitrogen, oxidized nitrogen and chloride). The total number of facilities sampled was 21, nine of which received only domestic (including commercial and institutional) wastewater; 12 received a mixture of domestic and industrial wastewater. In addition, data were obtained from independent sources for two domestic/industrial lagoon systems located in Everett, WA and Muskegon, MI (which were not part of the sampling program). The initial phase of sampling, conducted in August-November 1985, included nine domestic lagoons and one domestic/industrial lagoon (Mandan, ND). The remaining 11 domestic/industrial lagoons were sampled in July and August of 1986.

The nine domestic lagoons sampled as part of this program vary in size from 4 to 717 acres, with design flow rates of 0.19-5.0 mgd (actual flow rates were slightly lower). One lagoon is unlined; others have liners constructed of bentonite, compacted clay, or compacted earth. Specific information on each of the domestic lagoons is presented in Table 3-3.

The domestic/industrial lagoons sampled as part of this program vary in size from 8.5 to 368 acres, with design flow rates of 0.19-42.0 mgd. Three of the lagoons were being operated at rates above their design flow. All 12 lagoons sampled have some sort of liner; the most common is compacted earth. One lagoon system (Minong, WI) has a synthetic liner. Specific information on the 14 domestic/industrial lagoons (including those at Everett and Muskegon) is presented in Table 3-4.

3.5.3 Sampling and Analytical Procedures

Samples taken at the domestic sites included influent, lagoon wastewater, effluent, sludge and ground water. Based on the observed chemical similarity of the lagoon wastewater with the effluent, lagoon wastewater was not sampled at the domestic/industrial sites. Therefore, the three types of samples taken at domestic/industrial facilities were influent, effluent and sludge. The types of samples taken at each lagoon are listed in Table 3-5. All samples were taken on a single day, as extended periods of sampling were not possible. Consequently, variations with time in wastewater characteristics could not be determined.

Influent sampling used automatic composite samplers (composites varied from 6 to 24 hours) for all pollutants except volatile organics, cyanide and total phenols, for which grab samples were taken. Lagoon wastewater, effluent, sludge and groundwater samples were all taken on a grab basis. Further details on the lagoon sampling procedures are presented in Appendix 3.5. The methods and the quality assurance/quality control procedures employed by the laboratories are discussed in Appendix 3.5, as are the analytical pollutant detection limits.

TABLE 3-3

DOMESTIC LAGOONS SAMPLED

Site	Lagoon Type/ Discharge Mode	Flow (mgd)		Liner	Total Acreage
		Design	Actual		
Honeybrook, PA	Facultative with tertiary aeration; seasonal/controlled discharge	0.6	0.28	Double bentonite	9.5
Britton Village, MI	Facultative; seasonal/ controlled discharge	0.19	0.07	Compacted earth	19.9
Potterville, MI	Aerated/Facultative in series; seasonal/controlled discharge	0.45	<0.45	Compacted clay	45.2
Standish, MI	Facultative; seasonal/ controlled discharge	0.30	0.20 (0.46 with I/I)	Compacted clay	32.6
Minot, ND	Facultative; seasonal/ controlled discharge	NA	3.5	Compacted clay	717
McVille, ND	Facultative; seasonal/ controlled discharge	NA	0.06 (estimate)	None	4
Laramie, WY	Aerated lagoon with percolation beds and underdrain collection system	5.0	4.2	Bentonite	54.9
Lander, WY	Aerated; continuous discharge	NA	2.0	Bentonite	70
Buffalo, WY	Aerated; continuous discharge	NA	1.3	Bentonite	35

TABLE 3-4

DOMESTIC/INDUSTRIAL LAGOONS SAMPLED

Facility	Total Flow (mgd) Design	 Actual	Percent Industrial Flow	Total Acreage	Lining Type	Identified Industries
Hebron, IL	0.19	0.26	77	10.3	Compacted earth	Meat packing[b], zinc plater
Dexter, MO	0.45	0.30	78	31.7	Compacted earth	Oil filter manufacturer, automotive exhaust system manufacturer metal plater
Atkins, AK	0.75[a]	0.25	88	48.0	Compacted earth	Pickling[b], metal plating
Hattiesburg, MS	11.6	9.0	40	368.0	Compacted earth	Poultry processor, resin manufacturer
Alexandria, LA	14.0	9.5	5	53.5	Clay	Wood preserver[b], industrial laundry, aluminum
Glendive, MT	1.3	0.93	2	70.2	Compacted earth	Soft drink bottling plant, dairy, railroad yard
Scottsbluff, NE	3.1	3.9	15	128.0	Compacted earth	Meat packing[b], industrial laundry
Minong, WI	0.3	0.09	11	11.3	PVC/bentonite clay	Meat packing
Ridgecrest, CA	4.4	4.25	55	216.0	Compacted earth[c]	Military base (commercial), evaporative cooler return
Mandan, ND	0.96[a]	1.5	3	28.4	Compacted earth	Creamery, meat packing, bottling plant
Andrews SC	1.6[a]	0.91	29	17.0	Compacted earth	Textiles[b], wire products[b]
Pickens, SC	0.6[a]	0.26	75	8.5	Compacted earth	Metal plating[b], textiles
Everett, WA	31.0	12.5	5	230.0	Compacted earth	Metal plating[b], metal fabricators[b]
Muskegon, MI	42.0	33.0	70	172.4	Cement/clay	Pulp and paper plant[b], chemical and pharmaceutical manufacturers[b]

[a] Per EPA 1984 Needs Survey (Reference 6).

[b] Pretreatment provided.

[c] Some ponds sealed with bentonite and soda ash.

For all analyses, except the extractable organics, analytical detection limits were similar for all three laboratories, generally in the 1 to 10 parts per billion (ppb) range. However, detection limits for extractable organics fell into two distinct categories. Samples from 12 lagoons (9 domestic and 3 domestic/industrial) were analyzed at detection limits of 10-200 ug/l (liquid samples) and 10-250 ug/g (sludge samples). The remaining nine lagoons, however, were analyzed down to limits of 0.1-1.8 ug/l (wastewater) and 0.001-0.16 ug/g (sludge). Although the individual analytical detection limits for the first group (made up primarily of domestic lagoons) were found to be near the lower end of the ranges above, the difference in limits complicates comparison of extractable organics results for the two types of lagoons.

3.5.4 Results of Domestic Lagoon Sampling Program

A summary of the analytical results for the domestic lagoon sampling program is presented in Appendix 3.5 (Tables 3.5-1 and 3.5-2). Results for individual lagoons are also presented in Appendix 3.5. Before examining these data, it should be noted that the hydraulic residence times of the lagoon systems vary from three to over 180 days and thus influent values are only a "snapshot" of conditions at a given facility on the day of sampling. Therefore, those values may not represent typical influent quality and must be interpreted with care. In contrast, the lagoon wastewater, effluent and sludge concentrations are likely to provide a better representation of steady-state, long-term conditions, notwithstanding their grab-sample basis. (This conclusion is based on the assumption that the lagoons are relatively well-mixed and that lagoon sludge has accumulated over a long period of time).

Thirty-five of the 126 priority pollutants were detected at the nine domestic lagoons. Of the organics, 11 volatiles, eight base/neutral extractables, one acid extractable, one pesticide, one PCB, and total phenols (not a priority pollutant) were present in at least one sample. Twelve of the priority pollutant metals, barium and cyanide were also detected. Sludge concentrations are on a wet-weight basis; percent total solids were between 7.2 and 21 percent. The number of pollutants detected by category and the number of lagoons in which one or more pollutants from each pollutant category were found are presented in Table 3-6. The number of lagoons in which one or more pollutants from each pollutant category were found is also shown in Table 3-6.

Based on results for all domestic sample types, barium and the following 17 priority pollutants were detected in more than 10 percent of the samples obtained from the domestic lagoons:

- Benzene
- Chloroform
- Tetrachloroethylene
- Toluene
- Trichloroethylene
- Phenol

TABLE 3-5

LAGOON SAMPLING POINTS

Site	Wastewater Composition		Samples Collected				
	Domestic	Domestic/ Industrial	Lagoon Influent	Lagoon Effluent	Lagoon Wastewater	Monitoring Wells	Lagoon Sludge
Honeybrook, PA	x		x		x	x	x
Britton Village, MI	x		x	x	x	x	x
Potterville, MI	x		x	x	x	x	x
Standish, MI	x		x	x	x	x	
Minot, ND	x		x	x	x	x	x
McVille, ND	x		x		x	x	x
Laramie, WY	x		x	x	x	x	x
Lander, WY	x		x	x	x	x	x
Buffalo, WY	x		x		x	x	x
Mandan, ND		x	x	x	x	x	x
Hebron, IL		x	x	x			x
Dexter, MD		x	x	x			x
Atkins, AK		x	x	x			x
Hattiesburg, MS		x	x	x	x		x
Alexandria, LA		x	x	x			x
Glendive, MT		x	x	x			x
Scottsbluff, NE		x	x	x			x
Minony, WI		x	x	x			x
Ridgecrest, CA		x	x	x	x		x
Andrews, SC		x	x	x			x
Pickens, SC		x	x	x			x
Everett, WA[a]		x	x	x		x	x
Muskegon, MI[b]		x	x	x		x	x

[a] Not sampled as part of this study; data obtained from Reference 9.
[b] Not sampled as part of this study; data obtained from References 10, 11 and 12.

- Arsenic
- Cadmium
- Chromium
- Copper
- Lead
- Mercury
- Nickel
- Selenium
- Silver
- Thallium
- Zinc

Of the 18 pollutants, all but two (nickel and selenium) were present in 10 percent or more of the influent samples. Organic pollutant concentrations were as high as 280 ug/l (toluene) and metals were found at levels up to 228 ug/l (zinc). Only four of the volatile organics were found in lagoon effluent along with six of the metals, at concentrations up to 9.6 ug/l (toluene) and 117 ug/l (zinc), respectively.

Results for monitoring well samples included one of the above organics (phenol at 4.8 ug/l) and seven of the metals. The two metals with the highest concentrations were zinc at 10,600 ug/l, followed by lead at 740 ug/l. Nickel, found in ground water, was not detected in either influent or effluent samples. This observation can be tentatively attributed to either of two causes: (1) presence of these three metals in lagoon sludge, accumulated from wastewater received in the past; or (2) a non-lagoon source. Given the occurrence of nickel and other metals in the sludge (the highest being copper at 2,100 ug/g, barium at 1,482 ug/g and lead at 574 ug/g) and the frequency with which they were detected (10 of the above 12 metals were found in over 10 percent of the sludge samples taken), the former premise is more likely. Nonetheless, it is not possible to attribute definitive levels of these metals to contamination from the lagoons sampled. Although the data compiled as part of the domestic lagoon sampling program indicate the possibility of contamination of ground water, several limitations must be placed on interpretation of these data:

- Because the monitoring wells were often located close to the lagoon, wells designated as "upgradient" may actually be affected by lagoon seepage;

- At least one lagoon (McVille, ND); was located downgradient of a landfill or other "non-lagoon" source; and

- "Downgradient" wells were located too close to the site in most cases for the analytical results to represent ground-water quality at water supply wells, usually located further downgradient. On the other hand, they were not necessarily located close enough to represent actual seepage concentrations.

TABLE 3-6

FREQUENCY OF OCCURRENCE BY SAMPLE TYPE: DOMESTIC LAGOONS

Pollutant Category	Number of Lagoons with Detectable Concentrations of One or More Pollutants[a]			
	Lagoon Influent[b]	Lagoon Effluent[b,c]	Lagoon Sludge[b]	Monitoring Wells[b]
Volatile Organics (28)[d]	9 (9)	5 (6)	3 (2)	6 (8)
Acid Extractable Organics (11)[d]	3 (1)	1 (1)	0 (0)	2 (1)
Base/Neutral Extractable Organics (46)[d]	3 (5)	2 (2)	1 (3)	3 (5)
PCBs/Pesticides (25)[d]	0 (0)	1 (1)	1 (1)	0 (0)
Metals (13)[d,e]	9 (9)	7 (6)	8 (11)	9 (10)
Cyanide, Total Phenols (2)[d,f]	9 (1)	6 (2)	0 (0)	4 (1)

[a] Out of a total of 9 domestic lagoons.

[b] The number in parentheses is the number of pollutants detected in one or more lagoons (or associated monitoring wells).

[c] Includes lagoon wastewater.

[d] ( ) = Total number of priority pollutants tested in a given category.

[e] Excludes barium which is not a priority pollutant.

[f] "Total phenols" is not a priority pollutant parameter.

An overview of the sampling data indicates that metals tended to accumulate in the sludge layer, and were more likely to be found in ground water than were the volatile organic compounds. In contrast, volatile organics were detected more often in the effluent and less often in ground water.

To provide a point of reference for the sampling results discussed in this section, Table 3-7 presents health risk thresholds based on available Maximum Contaminant Levels (MCLs), risk specific dose (RSD) and reference dose (RfD) applicable to the pollutants detected in the nine domestic lagoons. A description of those three thresholds is provided in Chapter 2 of this report. Table 3-7 also presents the number of domestic lagoons in which effluent or lagoon wastewater concentrations exceed the thresholds.

3.5.5 Results of Domestic/Industrial Lagoon Sampling

Analytical results for the domestic/industrial lagoon sampling program are presented in Appendix 3.5 (Tables 3.5-3 and 3.5-4). Results for individual lagoons are also presented in Appendix 3.5.

Ninety-four of the 126 priority pollutants, barium and total phenols were detected based on the data collected from the 14 domestic/industrial lagoon systems including Muskegon, MI and Everett, WA (References 9, 10, 11 and 12). The number of priority pollutants detected by category and the number of lagoons in which one or more pollutants from each pollutant category were found are shown in Table 3-8. This table indicates that volatiles are the only pollutants consistently detected more often in lagoon influent than other types of samples. This result is logical because volatiles tend to diffuse to the atmosphere during treatment. Almost all other pollutants are observed in lagoon effluent and sludge with the same frequency as in the influent.

The information presented in Table 3-8 and Appendix 3.5 indicates that individual pollutants were detected with much greater frequency and at higher concentrations in domestic/industrial lagoons than in domestic lagoons. A discussion of the maximum concentrations found in domestic/industrial influent, effluent and sludge is presented below. Ground-water monitoring data are not presented, as 11 of the 14 domestic/industrial lagoons included in this study did not have ground-water monitoring wells installed.

3.5.5.1 Domestic/Industrial Lagoon Influent. In general, maximum volatile organics concentrations were on the order of 10 to 1,000 ug/l in lagoon influents. Toluene was the highest at 1,964 ug/l, followed by chloroform at 747 ug/l, and 1, 2-dichloroethane at 730 ug/l (one sample). Maximum concentrations of acid-extractable organics were consistently on the order of 100 ug/l, except for pentachlorophenol (828 ug/l) and 2-chlorophenol (742 ug/l). Maximum concentrations for base/neutral extractable organics were somewhat lower, on the order of 10-100 ug/l, with minimum detected concentrations often less than 1 ug/l.

Maximum metals concentrations generally ranged from 10 to 100 ug/l. However, zinc concentrations, the highest observed, varied from a minimum detected value of 155 ug/l to a maximum of 4,670 ug/l.

TABLE 3-7

SELECTED SAMPLING RESULTS vs HUMAN HEALTH-BASED THRESHOLDS: DOMESTIC LAGOONS

Pollutant Category/ Pollutant	Human Health-Based Thresholds (ug/l)		No. of Domestic Lagoons with Exceedances[c]			
			Lagoon Effluent[j]		Ground Water	
	MCL[a]	Other Threshold[b]	MCL	Other	MCL	Other
VOLATILES						
Benzene	5	-	0	-	0	-
Ethylbenzene	-[d]	3,500[e]	-	0	-	0
Chloroform	100[f]	0.430	0	4	0	1
Bromodichloromethane	-	14[e]	-	0	-	0
Tetrachloroethylene	-[g]	0.686	-	2	-	1
Toluene	-[g]	0,500[e]	-	0	-	0
1,1-Dichloroethane	-	2,840[e]	-	0	-	0
1,1,1-Trichloroethane	200	-	0	-	0	-
Tricnloroethylene	5	-	0	-	0	-
Methylene Chloride	-[g]	2.50	-	0	-	1
EXTRACTABLE ORGANICS						
Phenol	-	3,400[e]	-	0	-	0
Diethyl Phthalate	-	455,000[e]	-	0	-	0
Bis(2-ethylhexyl) Phthalate	-	3.85	-	0	-	1
1,4-Dichlorobenzene	75	-	0	-	0	-
1,2-Dichlorobenzene	-[g]	3,150[e]	-	0	-	0

TABLE 3-7, Continued

SELECTED SAMPLING RESULTS vs HUMAN HEALTH-BASED THRESHOLDS: DOMESTIC LAGOONS

Pollutant Category/ Pollutant	Human Health-Based Thresholds (ug/l)		No. of Domestic Lagoons with Exceedances[c]			
			Lagoon Effluent[j]		Ground Water	
	MCL[a]	Other Threshold[b]	MCL	Other	MCL	Other
PCBS/PESTICIDES						
Lindane (gamma-BHC)	4	-	1	-	0	-
METALS						
Antimony	-[g]	14[e]	-	0	-	0
Arsenic	50	-	0	-	0	-
Barium[h]	1,000	-	0	-	0	-
Beryllium	-[g]	17.2[e]	-	0	-	0
Cadmium	10	-	0	-	0	-
Chromium	50	-	0	-	0	-
Copper	-[g]	1,300[i]	-	0	-	0
Lead	50	-	0	-	3	-
Mercury	2	-	0	-	0	-
Nickel	-[g]	350[e]	-	0	-	0
Selenium	10	-	0	-	1	-
Silver	50	-	0	-	0	-
Thallium	-[g]	14[e]	-	0	-	0
Zinc	-	7,300[e]	-	0	-	1
OTHER						
Cyanide	-[g]	750[i]	-	0	-	0

TABLE 3-7, Continued

SELECTED SAMPLING RESULTS vs HUMAN HEALTH-BASED THRESHOLDS: DOMESTIC LAGOONS

Pollutant Category/ Pollutant	Human Health-Based Thresholds (ug/l)		No. of Domestic Lagoons with Exceedances[c]			
			Lagoon Effluent[j]		Ground Water	
	MCL[a]	Other Threshold[b]	MCL	Other	MCL	Other
Non-Conventional Pollutants						
NO_2/NO_3-N[h]	10,000	-	0	-	0	-

Notes:

[a] Maximum Contaminant Level.

[b] Unless noted otherwise, values are based on Risk Specific Doses (RSDs) for either the 10^{-6} incremental cancer risk level (Group A and B carcinogens) or the 10^{-5} level (Group C carcinogens).

[c] Out of a total of nine domestic lagoons.

[d] "-" indicates MCL not available or other thresholds not applicable to the study.

[e] Based on a Reference Dose (RfD) for noncarcinogens.

[f] Total trihalomethanes (THMs) cannot exceed 100 ug/l. If other THMs are present, this limit will be lowered proportionally. Therefore an RSD-based value specific to chloroform is also presented.

[g] MCLs and MCLGs will be promulgated for these pollutants by June 1989.

[h] Not a priority pollutant.

[i] Maximum Contaminant Level Goal (MCLG).

[j] Includes lagoon wastewater and lagoon effluent.

TABLE 3-8

FREQUENCY OF OCCURRENCE BY SAMPLE TYPE: DOMESTIC/INDUSTRIAL LAGOONS

Pollutant Category	Number of Lagoons with Detectable Concentrations of One or More Pollutants[a]		
	Lagoon Influent[b]	Lagoon Effluent[b,c]	Lagoon Sludge[b]
Volatile Organics (28)[d]	14 (23)	10 (19)	11 (15)
Acid Extractable Organics (11)[d]	13 (11)	10 (10)	9 (11)
Base/Neutral Extractable Organics (46)[d]	12 (43)	13 (38)	10 (41)
PCBs/Pesticides (25)[d]	1 (1)	2 (2)	0 (0)
Metals (13)[d,e]	13 (13)	13 (13)	13 (13)
Cyanide, Total Phenols (2)[d,f]	9 (2)	9 (2)	9 (2)

[a] Out of a total of 14 domestic/industrial lagoons.
[b] The number in parentheses is the number of pollutants detected in one or more lagoons.
[c] Includes lagoon wastewater.
[d] ( ) = Total number of priority pollutants tested in a given category.
[e] Excludes barium which is not a priority pollutant.
[f] "Total phenols" is not a priority pollutant parameter.

3.5.5.2 Domestic/Industrial Lagoon Effluent. Most volatile organics were found in lagoon effluent at concentrations below 35 ug/l, with the exception of 1,2-dichloroethane (164 ug/l), methylene chloride (280 ug/l), and chloroform (86 ug/l). Compared with lagoon influent, acid extractable organics concentrations decreased to less than 100 ug/l for all but three compounds (4-nitrophenol; 2,4-dinitrophenol and pentachlorophenol). Base/neutral extractable organics concentrations did not decrease as much, although fewer compounds were found at levels exceeding 100 ug/l.

Overall, metals concentrations appeared to be slightly lower in the effluent than in the influent, although some metals were found to have higher effluent concentrations. One extremely high observed value, 5,103.6 ug/l for nickel, is likely erroneous; the next highest value for nickel is 30.1 ug/l (Appendix 3.5).

Table 3-9 shows the number of domestic/industrial lagoons for which human health-based thresholds were found to be exceeded by pollutant concentrations in lagoon wastewater and effluent.

3.5.5.3 Domestic/Industrial Lagoon Sludge. As expected, maximum sludge concentrations for non-volatile organics were much greater than those for volatile organics (by two to four orders of magnitude). The two exceptions were toluene, with a maximum concentration of 3,330 ug/kg, and chlorobenzene, at 3,700 ug/kg.

Maximum metals concentrations were also high, varying up to 1,034 ug/g (1,034,000 ug/kg) for copper and 1,176 ug/g (1,176,000 ug/kg) for zinc. Other metals with maximum sludge concentrations exceeding 100 ug/g (100,000 ug/kg) included barium, chromium, lead and nickel.

3.5.6 Comparison of Results from Domestic and Domestic/Industrial Lagoons

A greater number of pollutants was detected in the domestic/industrial lagoons than in the domestic lagoons. In particular, 44 of the 46 base/neutral extractable organics were detected in the domestic/industrial systems versus only eight in the domestic systems. This indicates the impact of industrial contributions on raw wastewater quality. Additionally, all classes of compounds, both organics and metals, were detected at higher levels in the domestic/industrial lagoons.

A comparison of Tables 3-7 and 3-9 shows that effluent from the domestic/industrial lagoons has a greater number of pollutants with concentrations exceeding the applicable human health thresholds than effluent from domestic lagoons. Of the pollutants for which MCLs were available (see Tables 3-7 and 3-9), one or more were found in concentrations exceeding their respective MCLs in one domestic lagoon and seven domestic/industrial lagoons. For those pollutants without MCLs, one or more exceeded the health thresholds calculated on the basis of RSDs or RfDs in two domestic lagoons (four lagoons if the RSD-based threshold for chloroform is used instead of the MCL for total trihalomethanes) and 12 domestic/industrial lagoons.

TABLE 3-9

SELECTED SAMPLING RESULTS vs HUMAN HEALTH-BASED THRESHOLDS: DOMESTIC/INDUSTRIAL LAGOONS

Pollutant Category/ Pollutant	Human Health-Based Thresholds (ug/l)		No. of Domestic/Industrial Lagoons with Exceedances (Lagoon Effluent)[c]	
	MCL[a]	Other Threshold[b]	MCL	Other
VOLATILES				
Acrylonitrile	-[d]	0.0667	-	2
Benzene	5	-	3	-
Ethylbenzene	-	3,500[e]	-	0
Carbon Tetrachloride	5	-	0	-
Chloroform	100[f]	0.430	0	3
Chlorobenzene	-[g]	945[e]	-	0
Bromodichloromethane	-	14[e]	-	0
Tetrachloroethylene	-[g]	0.686	-	2
Toluene	-[g]	10,500[e]	-	0
1,1-Dichloroethane	-	2,840[e]	-	0
1,1-Dichloroethylene	7	-	0	-
1,2-Dichloroethane	5	-	1	-
1,1,1-Trichloroethane	200	-	0	-
1,1,2-Trichloroethane	-[g]	0.614	-	1
1,1,2,2-Tetrachloroethane	-	0.175	-	0
Trichloroethylene	5	-	0	-
Methylene Chloride	-[g]	2.50	-	2
Vinyl Chloride	2	-	0	-
EXTRACTABLE ORGANICS				
Acid				
Phenol	-	3,400[e]	-	0
2,4-Dichlorophenol	-	3,500[e]	-	0
2,4-Dinitrophenol	-	70[e]	-	1
Pentachlorophenol	-[g]	1,050[e]	-	0
2,4,6-Trichlorophenol.	-	1.75	-	5
Base/Neutral				
Benzidine	-	0.00015	-	3
Benzo (a) Anthracene	-	0.0130	-	0
Benzo (a) Pyrene	-	0.00303	-	1

TABLE 3-9 (continued)

SELECTED SAMPLING RESULTS vs HUMAN HEALTH-BASED THRESHOLDS: DOMESTIC/INDUSTRIAL LAGOONS

Pollutant Category/ Pollutant	Human Health-Based Thresholds (ug/l)		No. of Domestic/Industrial Lagoons with Exceedances (Lagoon Effluent)[c]	
	MCL[a]	Other Threshold[b]	MCL	Other
EXTRACTABLE ORGANICS, (Continued)				
Base Neutral (Continued)				
n-Nitrosodimethylamine	-	0.00135	-	1
n-Nitrosodiphenylamine	-	7.113	-	2
3,3'-Dichlorobenzidine	-	0.0207	-	1
Dimethyl Phthalate	-	350,000[e]	-	0
Fluoranthene	-	214[e]	-	0
Di-n-butyl Phthalate	-	45,500[e]	-	0
Diethyl Phthalate	-	455,000[e]	-	0
Bis(2-ethylhexyl) Phthalate	-	3.85	-	5
1,2-Dichlorobenzene	-[g]	3,150[e]	-	0
1,4-Dichlorobenzene	75	-	0	-
2,4-Dinitrotoluene	-	0.113	-	4
Isophorone	-	210[e]	-	0
Nitrobenzene	-	17.5[e]	-	0
Bis (2-chloroethyl) Ether	-	0.0307	-	3
Hexachlorobenzene	-	0.0210	-	5
Hexachlorobutadiene	-	0.452	-	0
Hexachloroethane	-	2.50	-	2
PCBs/PESTICIDES				
Lindane (gamma BHC)	4	-	0	-
OTHER				
Cyanide	-[g]	750[h]	-	0
METALS				
Antimony	-[g]	14[e]	-	1
Arsenic	50	-	1	-
Barium[f]	1,000	-	0	-
Beryllium	-[g]	17.2[e]	-	0
Cadmium	10	-	0	-
Chromium	50	-	0	-

TABLE 3-9 (continued)

SELECTED SAMPLING RESULTS
HUMAN HEALTH-BASED THRESHOLDS: DOMESTIC/INDUSTRIAL LAGOONS

Pollutant Category/ Pollutant	Human Health-Based Thresholds (ug/l)		No. of Domestic/Industrial Lagoons with Exceedances (Lagoon Effluent)[c]	
	MCL[a]	Other Threshold[b]	MCL	Other
METALS (Continued)				
Copper	-[g]	1,300[h]	-	0
Lead	50	-	0	-
Mercury	2	-	0	-
Nickel	-[g]	350[e]	-	1
Selenium	10	-	6	-
Silver	50	-	0	-
Thallium	-[g]	14[e]	-	1
Zinc	-	7,300[e]	-	0
NON-CONVENTIONAL POLLUTANTS				
NO_2/NO_3 - N[i]	10,000	-	0	-

Notes:

[a] Maximum contaminant level.

[b] Unless noted otherwise, values are based on Risk Specific Doses (RSD) for either the 10^{-6} incremental cancer risk level (Group A and B carcinogens) or the 10^{-5} level (Group C carcinogens).

[c] Out of a total of 14 domestic/industrial lagoons (includes lagoon wastewater and effluent).

[d] "-" indicates MCL not available or other thresholds not applicable to the study.

[e] Based on a Reference Dose (RfD) for noncarcinogens.

[f] Total trihalomethanes (THMs) cannot exceed 100 ug/l. If other THMs are present, this limit will be lowered proportionally. Therefore RSD values specific to chloroform are also presented.

[g] MCLs and MCLGs will be promulgated for these pollutants by June 1989.

[h] Maximum Contaminant Level Goal (MCLG).

[i] Not a priority pollutant.

Table 3-10 presents a general comparison of influent concentration ranges for the organic priority pollutants plus TOC detected in the domestic and domestic/industrial lagoon systems studied. This comparison shows that domestic/industrial raw wastewater contains higher concentrations of these organic pollutants than the domestic lagoons; maximum values of volatile organics in the domestic/industrial lagoons are approximately an order of magnitude higher, confirming the validity of developing two data bases for the national assessment. The same trend appears to hold true for extractable organics, although any comparison should take into account the difference in detection limits between the nine domestic lagoons and three of the domestic/industrial lagoons, and the remaining domestic/industrial lagoons.

A comparison of lagoon effluent concentration ranges for the organic pollutants is shown in Table 3-11. These data indicate higher effluent organic concentrations for the domestic/industrial lagoons than for the domestic lagoons.

3.5.7 Findings and Conclusions

- Based on the 1984 Needs Survey, the Nation has 5,476 municipal wastewater treatment lagoons of which about one-third are in the 12 Midwestern States.
- About 57 percent of the municipal lagoons treat wastewater flows of less than 0.1 million gallons per day (mgd), or a population equivalent of roughly 1000 persons, and only 4 percent handle flows over 1.0 mgd.
- 18 States require ground-water monitoring wells for lagoons under certain specific circumstances or based upon a case-by-case evaluation of their need. Five additional States require monitoring under specific conditions (e.g., unlined lagoon). Few municipal lagoons have monitoring wells and those few wells are not properly located to detect ground-water contamination.
- 12 States require linings for all lagoons, 18 States require linings as necessary to meet either State permeability criteria or case-by-case demonstration of need, 19 States have no specific lining requirements, and one State does not allow lagoons. Most municipal lagoons have linings of various types including compacted earth or clayey soils existing at the site.
- Seepage from lagoons, particularly those without linings, is difficult to predict or measure , even with costly soils tests.
- Of the nine domestic lagoons sampled, eight have earthen, clay or synthetic linings; all 12 domestic/industrial lagoons sampled have similar linings.
- Of the 5,476 municipal lagoons, 5,043 treat only domestic wastewater; the remainder treat combined domestic/industrial wastes.
- Based on a survey of commonly used household products, of EPA's 126 priority toxic pollutants, 23 (14 organics and nine metals) from eight household waste sources are commonly found in domestic wastewater.

TABLE 3-10

COMPARISON OF INFLUENT CONCENTRATION RANGES FOR ORGANIC POLLUTANTS

Pollutant Category	Influent Concentration Range (ug/l)	
	Domestic Lagoons	Domestic/Industrial Lagoons
Volatile Organics	<1 - 380	<1 - 1,964
Total Phenols[a]	18.5 - 238	5.7 - 260
Acid Extractable Organics	3.5 - 61	<1 - 828
Base/Neutral Extractable Organics	4 - 53	<1 - 1,430
TOC[a]	36 - 141	66 - 248

[a] Not a priority pollutant parameter.

TABLE 3-11

COMPARISON OF EFFLUENT CONCENTRATION RANGES FOR ORGANIC POLLUTANTS

	Effluent Concentration Range (ug/l)	
Pollutant Category	Domestic Lagoons	Domestic/Industrial Lagoons
Volatile Organics	<1 - 9.60	<1 - 280
Total Phenols[a]	13.3 - 78.8	1.4 - 204
Acid Extractable Organics	<1 - 5.1	<1 - 824
Base/Neutral Extractable Organics	<1 - 5.1	<1 - 235
TOC[a]	8.6 - 58.4	16.4 - 144

[a] Not a priority pollutant parameter.

- 35 of the priority pollutants were detected at one or more of the nine domestic lagoons sampled and 94 of the priority pollutants, generally with higher concentrations, were detected at several of the 14 domestic/industrial lagoons investigated. Priority pollutant concentrations, except for volatile organic compounds, were generally found to be one or more orders of magnitude greater in the sludge than in the effluent.

- The median effluent concentrations for the pollutants of concern were very low for all of the lagoons sampled; few of the pollutants had median values above their human health-based threshold concentrations and, in some cases, the median concentrations were lower than analytical detection limits.

- Of the pollutants for which MCLs were available, some were found in concentrations exceeding their respective MCLs in one domestic lagoon and seven domestic/industrial lagoons.

- Of those pollutants for which MCLs were not available, some exceeded the non-MCL health thresholds in two domestic lagoons (four lagoons if the RSD-based threshold for chloroform is used instead of the MCL for total trihalomethanes) and 12 domestic/industrial lagoons.

- Samples were taken at ground-water monitoring wells for the nine domestic lagoons and for the few domestic/industrial lagoons with ground-water monitoring wells. No definitive conclusions can be reached as to the degree of ground-water contamination actually caused by any of the lagoons sampled because: (1) most of the domestic/industrial lagoons lacked ground-water monitoring wells; (2) lagoon seepage likely affected data for the upgradient wells due to their proximity; and (3) the proximity of most downgradient wells did not provide an adequate and reliable representation of actual aquifer contamination at probable exposure points.

CHAPTER 3 REFERENCES

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CHAPTER 4

RESULTS OF ASSESSMENT OF POTENTIAL GROUND-WATER IMPACTS

As described in Chapter 2, the approach selected for the national assessment requires three categories of basic information: (1) lagoon waste characterization data (Chapter 3); (2) selection of pollutants and their human health-based threshold concentrations to serve as maximum concentration limits at the exposure point; and (3) hydrogeologic, geochemical and other parameters required for the EPACMS Monte Carlo simulation. Appendices 4.1, 4.2 and 4.3 contain detailed discussions of the methodologies for items (2) and (3).

4.1 MODEL OUTPUT

The input data for each of the 63 scenarios (seven pollutants in nine hydrogeologic categories) is included as Appendix 4.4, and the results of the computer runs are included as Appendices 4.5 and 4.6. These results are presented in two forms: dimensionless concentrations and target lagoon seepage concentrations. The initial output of EPACMS is in the form of a dimensionless concentration, defined as:

$$C_D = \frac{C_W}{C_{LS}}$$

where

C_D = dimensionless concentration

C_W = concentration in the well (i.e., at the exposure point)

C_{LS} = concentration in lagoon seepage (i.e., at the source).

If either C_{LS} or C_W is defined, and C_D is calculated by the model for a given set of input conditions (e.g., lagoon seepage rate, particle diameter, hydraulic gradient, etc.), the above equation will produce values of C_W or C_{LS}, respectively. The values of C_{LS} are based on maximum permissible well concentrations as defined in Chapter 2 (i.e., human health-based threshold concentrations).

4.2 LIMITATIONS OF COMPUTER RUN RESULTS

Any interpretation of computer run results must recognize the limitations inherent in the approach. These limitations can be divided into four types: (1) the state-of-the-art of computer modelling in general and the EPACMS code in particular ; (2) the assumptions concerning selection of input data applicable to the wide variety of lagoons and hydrogeologic regimes found in the United States; (3) operational constraints; and (4) use and interpretation of model output.

4.2.1 Computer Modelling and EPACMS

In general, computer modelling to estimate environmental impacts attempts to enable prediction of the effects (e.g., pollutant concentrations) likely to occur as a result of certain specified conditions. Because it is difficult to fully characterize the complex interactions occurring in nature (e.g., degradation, metal speciation, etc.), any model, no matter how complex, is a simplification of the world as it exists - a "best estimate." Therefore, whenever possible, modelling results should be compared with actual monitoring data to verify the accuracy of the model, its input data or both.

Unfortunately, the verification process for surface media (air, surface water) is simpler than that for ground water. Due to its great heterogeneity, the subsurface regime is extremely difficult to model, requiring the introduction of numerous assumptions (e.g., homogeneous media, absence of faults or other geologic phenomena, absence of confining layers, etc.). Once a model has been developed on the basis of these or similar assumptions and results for a specific site have been obtained, the verification process can be laborious due to the difficulty and expense encountered in obtaining data adequate in both number and quality for the subsurface regime.

In addition to the general problem of model verification, other issues include: (1) the assumption of steady-state conditions for this application (the model is not yet capable of addressing conditions of fully transient flow); (2) the exclusion of aerobic biodegradation from the model; and (3) the developmental nature of portions of the model.

The limitation of steady-state conditions has one major effect on this assessment: it is not possible to ascertain the time required, under a given set of hydrogeologic conditions, for a particular pollutant to reach the exposure point(s). That particular question may be suitable for further study at a later date.

The exclusion of aerobic biodegradation from EPACMS resulted from the difficulty of modelling aerobic conditions (e.g., oxygen transfer) in the subsurface environment. For those pollutants known to undergo aerobic biodegradation, this exclusion will result in overestimation of a pollutant's concentration as it reaches the saturated zone.

The third issue, the model's developmental nature, is best illustrated by the model's omission of metal speciation in the aqueous subsurface environment. These processes can be quite important under certain conditions, and their exclusion from this assessment can result in the generation of conservative (i.e., high) values of C_D for arsenic or any other metals specifically assessed. (A high value of C_D reflects a lower amount of dilution, transformation or degradation for a given pollutant, and thus a higher concentration at the exposure point.) One computer program for metal speciation, MINTEQ, is expected to be available soon.

4.2.2 Input Data

As presented in Appendix 4.1, several assumptions were made regarding numerous site-specific variables, including lagoon characteristics, site hydrogeology, and populations surrounding the lagoons. These assumptions include:

- Lagoon areas were estimated on the basis of flow data;

- The distance to the nearest exposure point was based on 220 (4 percent) of the national total of 5,476 lagoons;

- Lagoon seepage rates were estimated on the basis of State regulations, mass balance considerations, and limited field data from other sources;

- Chemical constants, particularly hydrolysis and biodegradation, were not available for all pollutants. Consequently the C_D values calculated by the model are conservative (i.e., high) showing only the effects of dilution for certain pollutants (e.g., arsenic); and

- Hydrogeologic parameters were compiled on the basis of expected regional characteristics. Such a compilation over-simplifies a region's hydrogeologic diversity.

The above limitations apply primarily to the saturated zone. The unsaturated zone, included as an option in EPACMS, was not used in the study. Although significant biological and chemical degradation can occur in the unsaturated zone, rate constants for these reactions, particularly biodegradation, were not available for most pollutants. Therefore, the unsaturated zone and its effects were omitted.

The necessary assumptions and estimates concerning input data affect the accuracy of the model. Since those assumptions are conservative, the C_D values generated by the model are likely to be higher than is actually the case, while the resulting C_{LS} concentrations are likely to be lower.

4.2.3 Use of EPACMS Results

Using the model output (a distribution of dimensionless concentration, C_D), for a given chemical and set of input parameters, a target pollutant source concentration can be determined if the maximum permissible well concentration, C_W, is known. This source concentration represents the concentration in the lagoon seepage, not necessarily the lagoon wastewater (or lagoon effluent, assuming a fully-mixed lagoon). Therefore, a procedure must be developed to correlate the calculated target seepage concentration for a pollutant with its lagoon effluent concentration.

The above exercise is difficult for a specific lagoon without actual data to develop a correlation. With the wide variety of lagoons, liners, and sludge layers (especially the thickness and chemical/biological characteristics of the sludge layers in the many lagoons), a generic relationship cannot be developed to describe physical, chemical and biological attenuation across the sludge layer, the lagoon liner or both. Therefore, this study assumes that lagoon effluent resembles lagoon seepage, a conservative assumption.

4.3 DISCUSSION OF RESULTS: DIMENSIONLESS CONCENTRATIONS

The results of EPACMS Run No. 2 are presented in Figure 4-1 (results for all other runs, except nitrate, are presented in Appendix 4.5). This graph shows the distribution of dimensionless concentration (C_D) values for hexachlorobenzene in Hydrogeologic Category 4.

The interpretation of Figure 4-1 begins with the selection of a cumulative frequency level of interest. A cumulative frequency level of 85 percent provides a reasonable representation of variation. Reading from the graph in Figure 4.1, this value corresponds to a C_D of 0.43. This observation means that, in 85 percent of the possible situations encountered in Hydrogeologic Category 4, C_D values will be less than or equal to 0.43. Using the relationship between C_D, C_W and C_{LS} as defined in Section 4.1, this statement can be expressed algebraically as:

$$C_W \leq 0.43\ C_{LS}$$

This relationship shows that hexachlorobenzene concentrations at typical exposure points will be less than or equal to 43 percent of the lagoon seepage concentrations in 85 percent of the situations encountered. C_D values for hexachlorobenzene and six other selected chemicals in the nine hydrogeologic categories are presented in Table 4-1. In general, these results fit within three pollutant groups, each discussed below.

4.3.1 Pollutants Undergoing Neither Hydrolysis nor Biodegradation

Five pollutants (hexachlorobenzene; tetrachloroethylene; benzene; 2,4-dinitrotoluene and arsenic) are included in this group. Because the model predicts steady-state, long-term conditions, retardation (as based on K_{OC} and other factors) does not affect the value of C_D in the absence of other degradation reactions (e.g., hydrolysis). Therefore, any attenuation that occurs can be viewed as due to purely physical factors, which can be loosely described as "dilution".

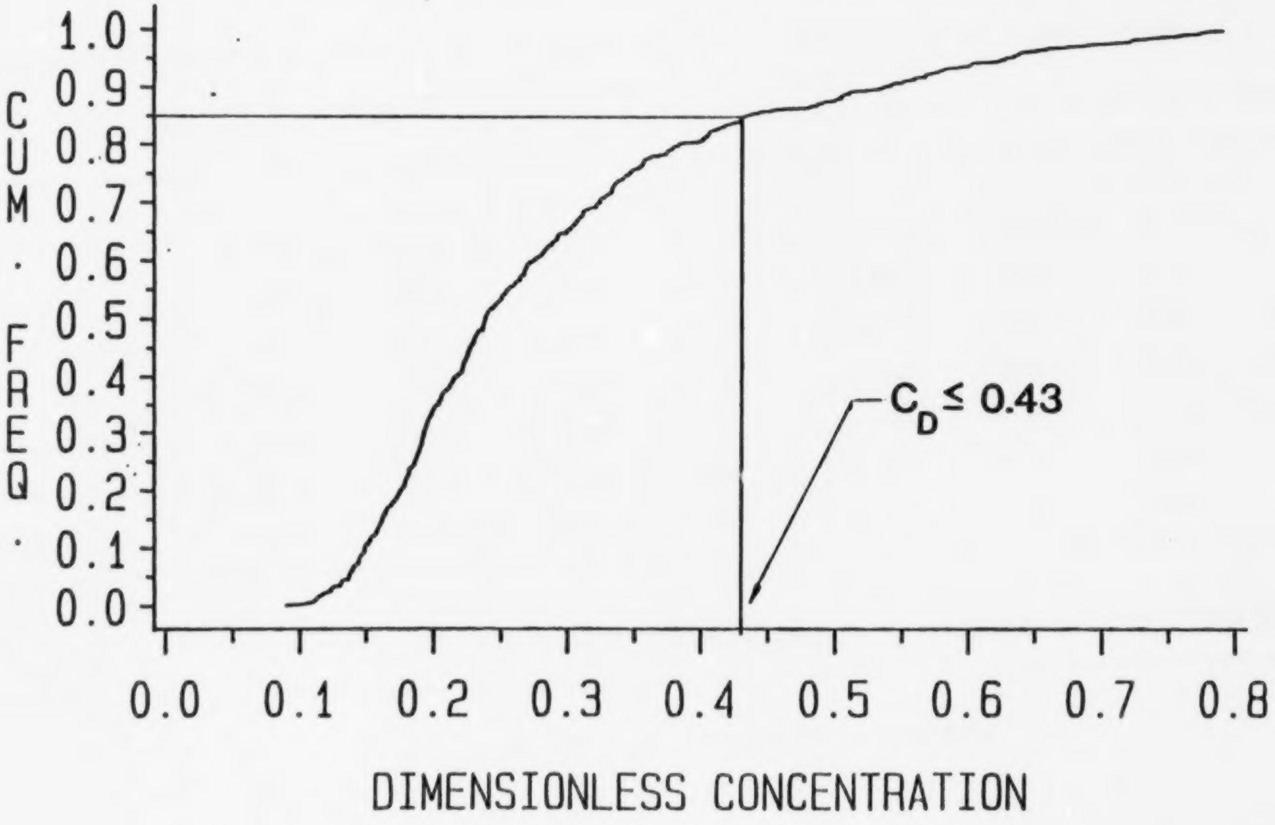
The overall trend apparent from Table 4-1 regarding these five pollutants is that of increasing dilution (i.e., lower C_D) with increasing velocity (see Appendix 4.1, Table 4.1-7). For example, Hydrogeologic Categories 3 and 4 have the highest estimated velocities and the lowest C_D values. This trend is modified somewhat by other variables such as aquifer thickness and infiltration, both of which affect the volume of ground water passing underneath and downgradient of the lagoon. Changes in these variables thus change the degree of dilution of the pollutants as they enter and are transported through the saturated zone. If the model were run in a transient mode, differences in contaminant arrival times due to velocity differences and retardation phenomena would also become apparent.

4.3.2 Pollutants Undergoing Hydrolysis but not Biodegradation

Only one pollutant, chloroform, belongs to this group. Table 4-1 shows that results for chloroform follow the same pattern with respect to dilution as the five pollutants above. Comparison of C_D values for chloroform with C_D values for

128995

FIGURE 4-1
EPACMS RUN No. 2 (C_D)
HEXACHLOROBENZENE - SATURATED ZONE ONLY
500 ITERATIONS - HYDROGEOLOGIC CATEGORY 4



JUNE 24, 1987

TABLE 4-1

MODEL RESULTS: DIMENSIONLESS CONCENTRATIONS

Chemical	C_D Value at 85% Cumulative Frequency Level for Hydrogeologic Categories 1 through 9[a,b]								
	1	2	3	4	5	6	7	8	9
Chloroform	0.70	0.77	0.54	0.42	0.62	0.80	0.76	0.73	0.75
Hexachlorobenzene	0.73	0.82	0.55	0.43	0.66	0.87	0.84	0.75	0.80
Tetrachloroethylene	0.73	0.82	0.55	0.43	0.66	0.87	0.84	0.75	0.80
Benzene	0.73	0.82	0.55	0.43	0.66	0.87	0.84	0.75	0.80
2,4-Dinitrotoluene	0.73	0.82	0.55	0.43	0.66	0.87	0.84	0.75	0.80
Arsenic	0.73	0.82	0.55	0.43	0.66	0.87	0.84	0.75	0.80
Nitrate[c]	2.59×10^{-15}	2.09×10^{-21}	4.83×10^{-11}	9.66×10^{-13}	2.16×10^{-17}	8.06×10^{-45}	4.08×10^{-50}	3.47×10^{-13}	3.97×10^{-34}

[a] Dimensionless concentration, C_D, equals the well (exposure point) concentration, C_W, divided by the lagoon seepage concentration, C_{LS}.

[b] Given the hydrogeologic and other parameters as defined for this category, 85% of the cases (i.e., lagoons) will have C_D values less than or equal to the specified value, under steady-state conditions.

[c] Due to limits on presentation of statistical data, nitrate values are for the 90% cumulative frequency level.

the pollutants discussed in Section 4.3.1 shows a slight decrease in C_D for chloroform within a given hydrogeologic category. (As expected, hydrolysis increases attenuation).

4.3.3 Pollutants Undergoinq Biodegradation but not Hydrolysis

Only one pollutant, nitrate, belongs to this group. The biodegradation rate constant, 3.2×10^{-6} second^{-1}, corresponds to a half-life of 2.5 days (0.0069 years). This rate is quite rapid, and would be expected to result in significant attenuation. That expectation was verified; in fact, the resulting C_D values were so low and covered such a wide range that they could not be displayed in graphical form (and thus no graphs are included in Appendix 4.5). Consequently the C_D values corresponding to an 85% frequency of occurrence could not be read as for the other pollutants; instead, C_D values for the 90% value (explicitly calculated by the available statistics program) are shown.

The interesting point to note for these nine runs was an approximate reordering of the hydrogeologic categories with respect to increasing dilution. For example, Categories 3 and 4, with the greatest degree of dilution due to purely hydrogeologic factors (see Section 4.3.1) exhibited the highest C_D values for nitrate. This reversal is due to the fact that biodegradation is modelled as a first-order reaction, dependent upon the initial concentration of the contaminant present in the aquifer. Therefore, the greater the degree of dilution by hydraulic phenomena, the lower the initial concentration (see Section 4.3.1), and thus the lower the degree of biodegradation.

4.4 DISCUSSION OF RESULTS: LAGOON SEEPAGE CONCENTRATIONS

The results of the computer runs as presented above were expressed in terms of C_D, a dimensionless concentration. To determine target lagoon (seepage) concentrations corresponding to a given maximum exposure point concentration, the C_D values must be transformed using the relationship between C_D, C_W and C_{LS} discussed above. This transformation (where the values for C_W are the human health-based threshold concentrations presented in Tables 3-7 and 3-9 for the seven chemicals being modelled), coupled with a rearrangement of the statistical presentation, results in distributions such as that shown for hexachlorobenzene in Figure 4-2.

The interpretation of these results differs from that of Figure 4-1. To find a target lagoon seepage concentration that will not result in exposure point exceedances more than 85% of the time, it is necessary to read the C_{LS} value corresponding to 15 percent (i.e., 1.00-0.85 = 0.15). For example, the C_{LS} corresponding to 15% on Figure 4-2 is 4.88×10^{-5} mg/1 (4.88×10^{-2} ug/1). This observation means that, of all possible situations encountered in Hydrogeologic Category 4, only 15% will result in an exceedence of the exposure point threshold (for hexachlorobenzene) of 2.1×10^{-2} ug/1, if the lagoon seepage concentration is less than or equal to 4.88×10^{-2} ug/1. This statement corresponds to an 85% probability that the exposure point concentration will not be exceeded if:

$$C_{LS} \leq 4.88 \times 10^{-2} \text{ ug/1.}$$

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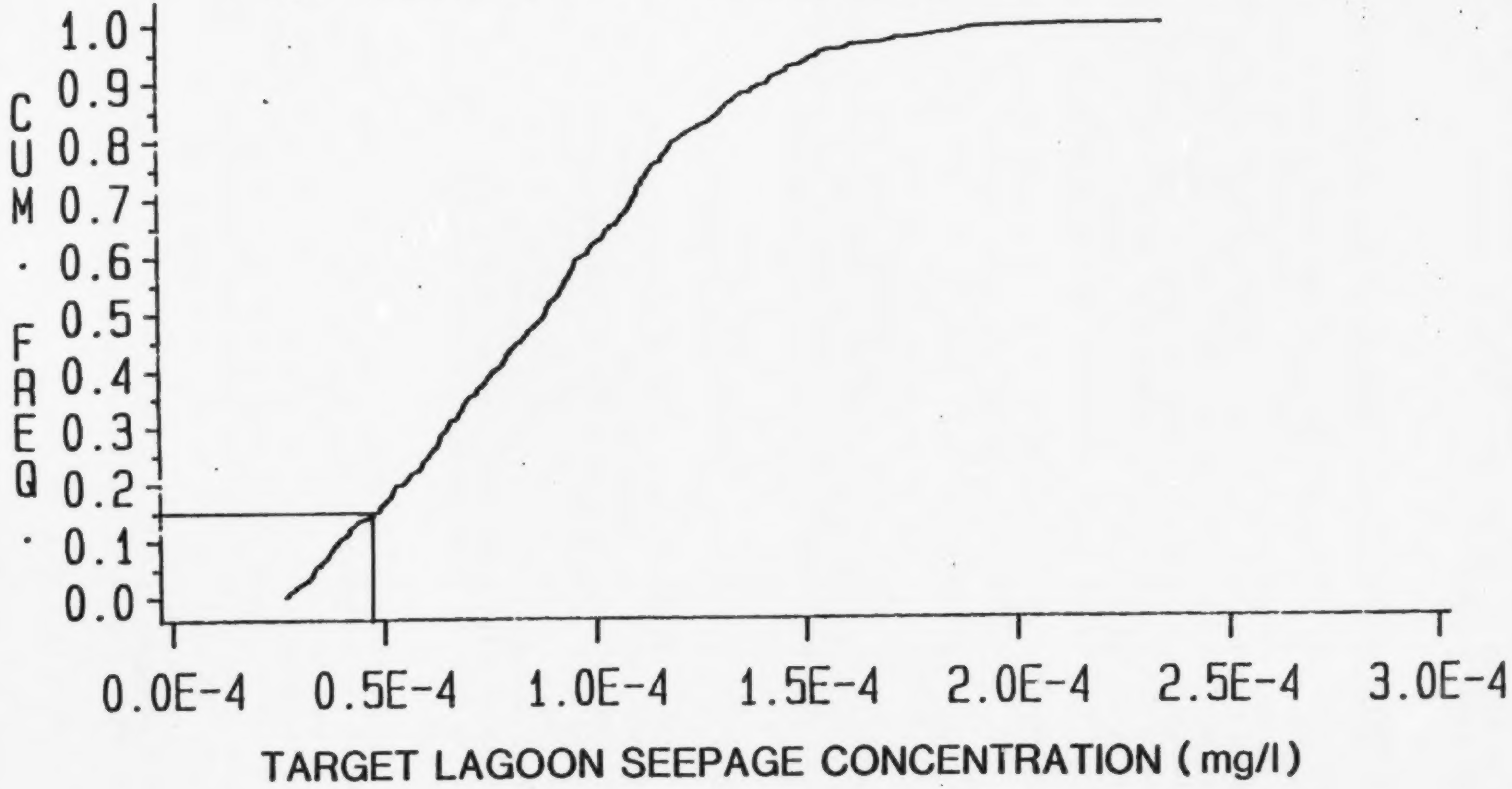
FIGURE 4-2

EPACMS RUN No. 2 (C_{LS})

HEXACHLOROBENZENE - SATURATED ZONE ONLY

500 ITERATIONS - HYDROGEOLOGIC CATEGORY 4



JUNE 23, 1987

The corresponding C_{LS} values for other categories and pollutants are presented in Table 4-2. These values are determined using on the human health-based thresholds discussed in Chapter 2.

Three of the seven pollutants modelled (benzene, arsenic and nitrate) had MCLs available for use as exposure point concentrations (C_w). Three other pollutants (hexachlorobenzene, tetrachloroethylene, and 2, 4-dinitrotoluene) did not have MCLs, and RSD-based concentrations are used as the exposure point values. The seventh chemical (chloroform), is part of a group of pollutants, trihalomethanes (THMs), for which an MCL of 100 ug/l has been established. (Thus, if other THMs are present, the allowable chloroform concentration would be proportionally reduced). Because this MCL includes several pollutants, not just chloroform, the RSD-based concentration specific to chloroform is also presented.

Of the four modelled pollutants for which MCLs were available (including chloroform/THMs), none were found in domestic lagoons at levels exceeding the computed target lagoon concentrations (based in a 10^{-6} incremental cancer risk). Two of the pollutants (arsenic and benzene) were found in concentrations above target levels in domestic/industrial lagoons; four of the 14 lagoons had concentrations of one or the other of these two pollutants in excess of the target levels. Modelling results for the remaining three pollutants without MCLS and chloroform were compared to lagoon concentrations on the basis of RSD-derived exposure point concentrations. Two of these compounds (tetrachloroethylene and chloroform) were found above target levels in domestic lagoons; while all four were above the completed C_{LS} values in domestic/industrial lagoons. Exceedances of the RSD-based target levels for one or more pollutants were observed in four domestic and nine domestic/industrial lagoons.

Tables 4-3 and 4-4 show the variation with hydrogeologic category of the number of domestic and domestic/industrial lagoons, respectively, with pollutant concentrations above the target levels. This variation is minimal for domestic lagoons (Table 4-3) with only one pollutant (tetrachloroethylene) showing fewer affected lagoons for locations with the characteristics of Hydrogeologic Categories 3 and 4 (high ground-water velocity). For domestic/industrial lagoons (Table 4-4), benzene and arsenic target concentrations are exceeded in fewer lagoons in the same two hydrogeologic categories.

4.5 INTERPRETATION OF RESULTS

In this study, limited lagoon sampling data were compared with the results of a computer modelling exercise to determine whether lagoon concentrations exceeded target levels for seven pollutants in nine hydrogeologic regimes. (These target lagoon concentrations, generated by the computer model, were predicated on selected human health-based threshold concentrations at a downgradient exposure point). Interpretation and application of study results should be made with care, for several reasons.

First, the results of the computer modelling exercise are likely to be conservative, given the numerous conservative assumptions required. Second, the selection of lagoon effluent data to represent lagoon seepage concentrations is also a conservative assumption. Finally, the data obtained during the lagoon sampling program are very limited and certainly do not represent a valid statis-

TABLE 4-2

MODEL RESULTS: COMPUTED TARGET LAGOON SEEPAGE CONCENTRATIONS BASED ON HUMAN HEALTH THRESHOLDS

Chemical	Computed Target Lagoon Seepage Concentrations, C_{LS}, (at 85% Cumulative Frequency Level) for Hydrogeologic Categories 1 through 9 (ug/l)[a,b]								
	1	2	3	4	5	6	7	8	9
Chloroform[c]									
MCL[d]	143	130	185	238	161	125	132	137	133
Other Threshold[e]	6.14×10^{-1}	5.58×10^{-1}	7.96×10^{-1}	1.02	6.94×10^{-1}	5.38×10^{-1}	5.66×10^{-1}	5.89×10^{-1}	5.73×10^{-1}
Hexachlorobenzene									
MCL	-	-	-	-	-	-	-	-	-
Other Threshold	2.88×10^{-2}	2.56×10^{-2}	3.82×10^{-2}	4.88×10^{-2}	3.18×10^{-2}	2.41×10^{-2}	2.50×10^{-2}	2.80×10^{-2}	2.63×10^{-2}
Tetrachloroethylene									
MCL	-	-	-	-	-	-	-	-	-
Other Threshold	9.26×10^{-1}	8.24×10^{-1}	1.23	1.57	1.02	7.77×10^{-1}	8.05×10^{-1}	9.01×10^{-1}	8.45×10^{-1}
Benzene									
MCL	6.85	6.10	9.09	11.63	7.58	5.75	5.95	6.67	6.25
Other Threshold	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene									
MCL	-	-	-	-	-	-	-	-	-
Other Threshold	1.55×10^{-1}	1.38×10^{-1}	2.05×10^{-1}	2.63×10^{-1}	1.71×10^{-1}	1.30×10^{-1}	1.35×10^{-1}	1.51×10^{-1}	1.41×10^{-1}
Arsenic									
MCL	68.5	61.0	90.9	116.0	75.8	57.5	59.5	66.7	62.5
Other Threshold	-	-	-	-	-	-	-	-	-
Nitrate[e]									
MCL	3.86×10^{18}	4.78×10^{24}	2.07×10^{14}	1.04×10^{16}	4.63×10^{20}	1.24×10^{48}	2.45×10^{53}	2.88×10^{16}	2.52×10^{37}
Other Threshold	-	-	-	-	-	-	-	-	-

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[a] Lagoon seepage concentration, C_{LS}, equals the well (exposure point) concentration, C_W, divided by the dimensionless concentration, C_D.

[b] 85% of the situations likely to be encountered in a given hydrogeologic category will not result in an exceedence of maximum allowable exposure point concentrations if the actual lagoon seepage concentration is less than the computed target value, C_{LS}.

[c] Both types of health thresholds are presented for chloroform, because the applicable MCL of 100 ug/l is for total trihalomethanes (THMs). If other THMs are present, the limit for chloroform will be proportionally lower.

[d] Maximum Contaminant Level (enforceable standard).

[e] Based on Reference Dose (non-carcinogens), Risk Specific Dose at 10^{-6} upperbound incremental risk level (carcinogens), or Maximum Contaminant Level Goals (non-enforceable criteria).

TABLE 4-3

NUMBER OF DOMESTIC LAGOONS WITH EFFLUENT OR WASTEWATER CONCENTRATIONS EXCEEDING THE COMPUTED TARGET CONCENTRATIONS FOR A GIVEN HYDROGEOLOGIC CATEGORY[a,b]

Pollutant/Criteria	Hydrogeologic Category 1	2	3	4	5	6	7	8	9
Chloroform									
MCL[c]	0	0	0	0	0	0	0	0	0
Other Threshold[d]	4	4	4	4	4	4	4	4	4
Hexachlorobenzene									
MCL	-[e]	-	-	-	-	-	-	-	-
Other Threshold	0	0	0	0	0	0	0	0	0
Tetrachloroethylene									
MCL	-	-	-	-	-	-	-	-	-
Other Threshold	2	2	1	0	2	2	2	2	2
Benzene									
MCL	0	0	0	0	0	0	0	0	0
Other Threshold	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene									
MCL	-	-	-	-	-	-	-	-	-
Other Threshold	0	0	0	0	0	0	0	0	0
Arsenic									
MCL	0	0	0	0	0	0	0	0	0
Other Threshold	2	2	2	2	2	2	2	2	2
Nitrate									
MCL	0	0	0	0	0	0	0	0	0
Other Threshold	0	0	0	0	0	0	0	0	0

---

[a] From a sample population of nine domestic lagoons.

[b] The computed target lagoon concentration is based on human health thresholds.

[c] Maximum Contaminant Level.

[d] Threshold is based on the Risk Specific Dose for the 10^{-6} risk level.

[e] Threshold value not available (MCL) or not applicable (RSD-based threshold).

TABLE 4-4

NUMBER OF DOMESTIC/INDUSTRIAL LAGOONS WITH EFFLUENT OR WASTEWATER CONCENTRATIONS EXCEEDING THE COMPUTED TARGET CONCENTRATIONS FOR A GIVEN HYDROGEOLOGIC CATEGORY[a,b]

Pollutant/Criteria	Hydrogeologic Category 1	2	3	4	5	6	7	8	9
Chloroform									
MCL[c]	0	0	0	0	0	0	0	0	0
Threshold[d]	3	3	3	3	3	3	3	3	3
Hexachlorobenzene									
MCL	-[e]	-	-	-	-	-	-	-	-
Threshold	5	5	5	5	5	5	5	5	5
Tetrachloroethylene									
MCL	-	-	-	-	-	-	-	-	-
Threshold	2	2	2	2	2	2	2	2	2
Benzene									
MCL	3	3	2	0	3	3	3	3	3
Threshold	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene									
MCL	-	-	-	-	-	-	-	-	-
Threshold	4	4	4	4	4	4	4	4	4
Arsenic									
MCL	1	1	0	0	1	1	1	1	1
Threshold	-	-	-	-	-	-	-	-	-
Nitrate									
MCL	0	0	0	0	0	0	0	0	0
Threshold	-	-	-	-	-	-	-	-	-

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[a] From a sample population of 14 domestic/industrial lagoons.

[b] The computed target lagoon concentration is based on human health thresholds.

[c] Maximum Contaminant Level.

[d] Threshold is based on the Risk Specific Dose for the 10^{-6} risk level.

[e] Threshold value not available (MCL) or not applicable (RSD-based threshold)

tical cross-section of the national lagoon population. Based on these three factors, direct comparisons of model results with lagoon sampling data may not be strictly valid.

Interpretation of the results and the above observations should be made with care, taking into account the following factors:

- There were no actual ground-water sampling data suitable for verification of the model;
- The lagoon characterization data used for comparison with computer modelling results were of a limited nature: only 23 of 5,476 lagoons were represented; 21 of which were sampled on a short-term (i.e., one-day) basis;
- The nine hydrogeologic regimes investigated in this study represent 4,895 (89%) of the national total of 5,476 lagoons (Appendix 4.1, Table 4.1-14); and
- A conservative approach was taken in conducting model runs and interpreting model results. This approach included (but was not limited to): (1) exclusion of the unsaturated zone from consideration due to unavailability of aerobic biological degradation parameters; (2) unavailability of chemical and anaerobic biodegradation rate constants for some of the pollutants, resulting in an overestimate of aerobic downgradient concentrations; and (3) the assumption that lagoon seepage concentrations were equal to lagoon liquid (effluent) concentrations.

Additionally, the results as shown represent steady-state conditions, and thus provide no information on the effects of retardation. For example, the transport of hexachlorobenzene in ground water is likely to be greatly retarded and the compound may not reach an exposure point in appreciable concentrations within the period of interest. As a result of these and other considerations dicussed in more detail throughout this chapter and in Appendix 4.1, any interpretation of Tables 4-1 through 4-4 must be made with care, and must recognize that the modelling results very likely overestimate the extent of potential contamination. Therefore, the numbers presented in these tables should be interpreted only on a relative basis, within the context of this study.

4.6 FINDINGS AND CONCLUSIONS

- Of the four modelled pollutants for which MCLs were available (including chloroform) none were found in domestic lagoons at levels exceeding the computed MCL-based target lagoon concentrations. Two of the four pollutants (arsenic and benzene) were found in domestic/industrial lagoons at concentrations exceeding MCL-based target levels. These exceedances occurred in four of the 14 domestic/industrial lagoons for which characterization data were available.

- Modelling results for the remaining three pollutants without MCLs (and chloroform) were compared to lagoon concentrations on the basis of RSD-derived exposure point concentrations. Two of these pollutants (tetrachloroethylene and chloroform) were found above target levels in at least one domestic lagoon, while all four were above target levels in some of the domestic/industrial lagoons. Exceedances of target levels for at least one of these four pollutants were observed in four domestic lagoons and nine domestic/industrial lagoons.

- Based on the sampling program and the modelling results, seepage from domestic/industrial lagoons is more likely to threaten contamination of nearby aquifers than seepage from similarly constructed and located domestic lagoons.

- Overall, lagoons receiving only domestic wastes appear unlikely to affect ground water enough to exceed the available MCLs at exposure points of interest.

CHAPTER 5

ASSESSMENT OF HUMAN HEALTH RISK

An assessment of human health risks associated with ground-water contamination from municipal lagoons was conducted in order to better understand the threats posed to existing populations on a regional and national basis. While the national assessment described in Chapter 4 examines scenarios in which municipal lagoons may pose a human health threat, this assessment of human health risks focuses on the magnitude and geographic distribution of these risks. The results of the risk assessment in this chapter can be used to support the conclusions of the national assessment concerning the role of preventive and corrective measures in reducing the potential health threat from lagoons.

This assessment was conducted using an approach generally consistent with that used to estimate protective (target) lagoon concentrations in Chapter 4. The data used to characterize lagoons, environmental settings, the location of potentially exposed populations, and pollutants were identical to those used in the national assessment, in order to ensure the comparability of the results from the two types of assessment. Like the national assessment, this assessment relies on several conservative assumptions and, therefore, generates upper-bound estimates of risks. The results of this assessment provide an alternative measure with which the threat posed by ground-water contamination from municipal lagoons can be judged.

The following overview of the health assessment approach describes the various technical components of the analysis and the sources of data. Next, the chapter discusses the modelling results followed by conclusions concerning the magnitude and distribution of health risks attributable to municipal lagoons. The chapter also presents the assumptions and limitations of the health assessment risks. A more detailed discussion of the risk assessment methodology is presented in Appendix 5.

5.1 OVERVIEW OF APPROACH

This assessment of human health risks is based upon an approach to modelling similar to that described in Appendix 4.1 A risk modelling approach was chosen for this analysis due to the scarcity of epidemiologic information on the incidence of either carcinogenic or noncarcinogenic effects that could be attributable to municipal lagoons. Accordingly, the analysis of the potential threat to persons residing within the vicinity of municipal lagoons draws extensively from both the data collection and modelling efforts begun in the national assessment (Chapter 4).

This health assessment examines cancer and noncancer health effects using two different measures of risk: a quantitative estimation of risks to the maximally exposed individual (MEI risks) and a qualitative discussion of population risks. These two measures provide different perspectives on the magnitude of the potential threat to human health posed by lagoons. MEI risks quantify the level of risk experienced by the person experiencing the highest level of exposure to contaminated drinking water and therefore receiving the highest risk. This measure of risk provides an indication of the maximum likelihood of contracting the relevant human health effect; by definition, this level would not affect the entire exposed population. Population risk can be used to estimate the total number of carcinogenic or noncarcinogenic cases that can be expected nationally or regionally from exposure to contaminated drinking water. Estimating population risks requires information on the distribution of exposed populations residing near wastewater treatment lagoons.

This health assessment examines risk both on a regional and national basis in order to highlight particularly vulnerable locations in the U.S., while developing an overall estimate of the risks that can be expected nationwide. First, risks are estimated for each of the pollutants of concern in each of the nine hydrogeologic settings. After aggregating risks across pollutants in order to generate a total risk for each of the environmental settings, the environmental setting risk results are weighted according to the frequency of occurrence of municipal lagoons within each environmental setting and summed to provide a national risk estimate. With this approach, it is possible to examine which pollutants pose the greatest threats while examining the geographic variability of risks.

In order to model risks from municipal lagoons, it is necessary to characterize five components impacting risks: 1) pollutant release rates from lagoons, 2) pollutant fate and transport in the environment, 3) distances to exposed populations, 4) health effects associated with the ingestion of contaminated ground water, and 5) frequency of occurrence of environmental settings. Each of these factors is discussed briefly below.

5.1.1 Pollutant Release Rates from Municipal Lagoons

Municipal lagoons release pollutants into ground water by seepage of leachate containing dissolved pollutants through the bottom sludge layer and into the surficial aquifer. In order to estimate the mass of each pollutant released to an underlying aquifer, it is necessary to quantify both the seepage rate of the lagoon and the concentrations of pollutants in the leachate. The estimate of seepage rates used here was identical to the values used in the national assessment and discussed in detail in Appendix 4.1.

Leachate concentrations from the lagoons were assumed to be equal to the effluent or lagoon liquid phase concentrations of the pollutants being modelled. As discussed in Chapter 3, data on lagoon effluent concentrations were collected for 23 municipal lagoon systems. Both median and maximum effluent concentrations reported in these data were modelled in order to characterize a range of representative lagoon seepage concentrations. In many cases, the median concentrations were based on analytical detection limits for all pollutants because concentrations were not quantified. Appendix 5.1 provides the leachate concentrations of the seven pollutants modelled in the assessment.

5.1.2 Pollutant Fate and Transport in the Environment

Fate and transport of pollutants released from municipal lagoons was modelled using an analytical computer model, EPACMS, coupled with a Monte Carlo driver for selecting the hydrogeologic and exposure distance input parameters described in Appendix 4.1. This health assessment used the same hydrogeologic and geochemical parameters described in Appendix 4.1, ensuring the consistency of the assumptions and limitations inherent to the approaches presented here and in Chapter 4. The modelling approach accounts for hydrolysis of organic pollutants where current geochemical data indicate this process to be significant for particular pollutants (See Appendix 4.3). Anaerobic degradation of nitrate was also simulated; the modelling approach did not account for any aerobic degradation processes. Because the modelling assumes steady-state conditions, pollutant mobility is only considered to the extent that it affects the concentrations of degradable pollutants.

Unlike the national assessment, which calculates protective lagoon leachate concentrations based upon exposure point concentration inputs to the ground-water transport model, the health assessment employs leachate concentrations as model inputs in order to generate estimates of contaminant concentrations at these potential exposure points.

5.1.3 Distance to Exposed Populations

The distance to a drinking water well is a critical input to the risk analysis because of the dependence of ground-water contaminant concentrations on distance from the pollutant source. Due to dispersion and degradation of contaminants in the aquifer, contaminant concentrations can decrease significantly as the distance from the lagoon increases. A mapping survey of 220 municipal wastewater treatment lagoons was conducted in order to characterize the distance to and numbers of potential receptors located within the vicinity of municipal lagoons nationwide.

A continuous function fitting the MEI distance distribution was developed to allow the distance to ground-water wells to be selected as a Monte Carlo input. This Monte Carlo modelling approach ensures that the estimated risks account for the variation in distances between lagoons and the closest downgradient drinking water well nationwide. A brief description of how the MEI exposure distance and population distance distributions were developed follows.

5.1.3.1 MEI Risk Exposure Distance Distribution. The MEI risk at a single lagoon can be estimated by determining ground-water concentrations at the closest well located downgradient from the lagoon and then calculating the risk to an individual consuming the contaminated ground water. A national distribution representing the distance to the closest well for the entire lagoon population was developed by combining the well distances estimated from 7.5-minute quadrangle maps for each of the 220 lagoons included in the mapping survey into one distribution.

The closest well on each map was assumed to be the nearest private residence downgradient from the lagoon in areas not served by public water supplies, or the nearest public well in locations served by public water. The dependence of the populace in the area surrounding each lagoon on public water was determined through the Federal Reporting Data System (FRDS), which was also used to locate public water supply wells.

5.1.3.2 Population Risk Exposure Distance Distribution. Population risks are discussed qualitatively in the health assessment based upon the survey information on total potentially exposed populations. In order to develop a national estimate of the population risks attributable to municipal lagoons, the total number of people potentially exposed to contaminated ground water in the sample of municipal lagoons was tabulated.

5.1.4 Estimating Risks to Exposed Populations

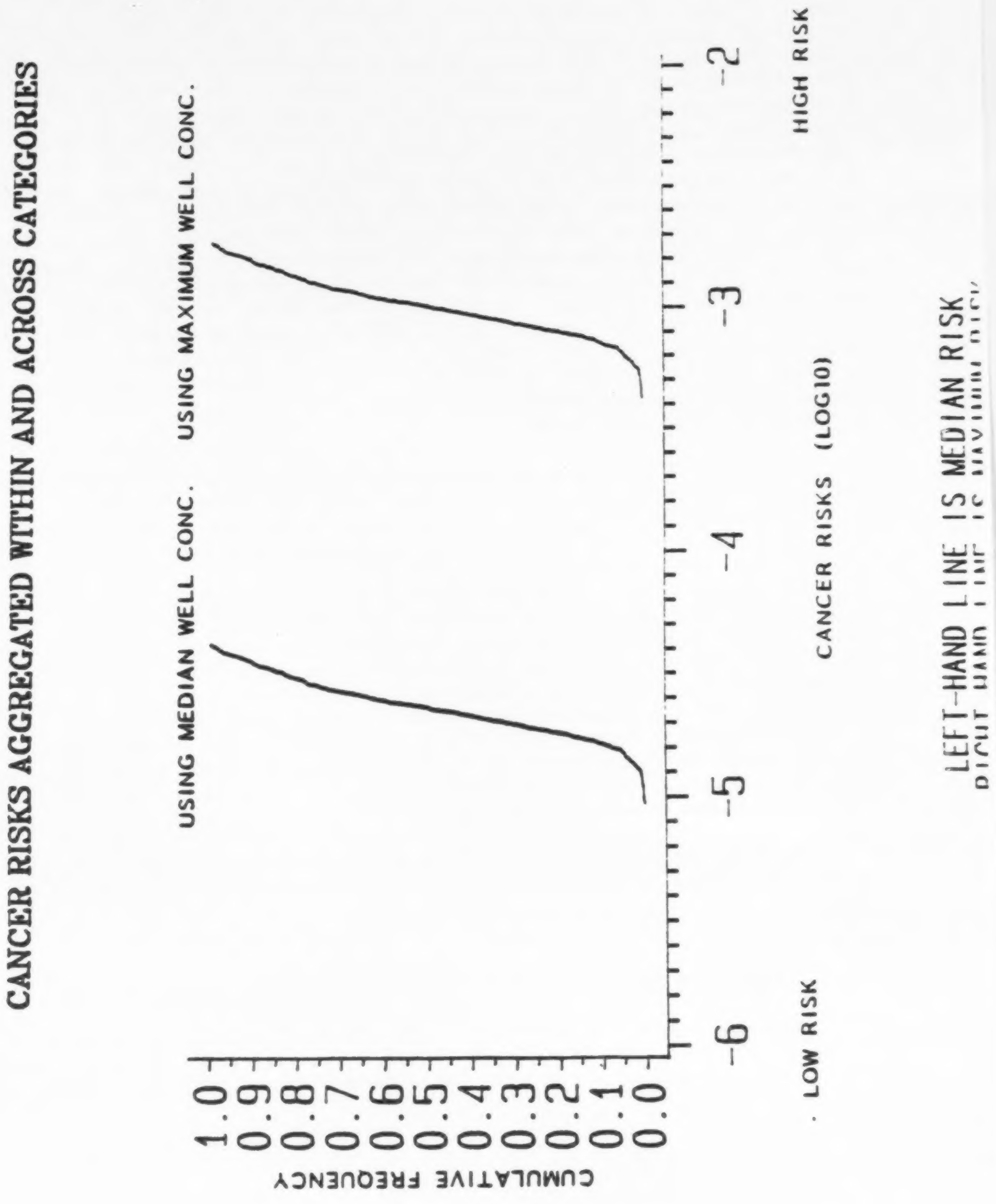
Once drinking water well concentrations are estimated with EPACMS, risks can be calculated using standard ingestion assumptions and health effects data (see Appendix 4.1.1). Ingestion rates are based on the assumption that an adult weighting 70 kilograms ingests 2 liters of contaminated water per day over a 70-year lifetime.

5.1.5 Aggregating Risks Across Environmental Settings

Once risks and hazards are calculated for each pollutant within each environmental setting (hydrogeologic category), the total carcinogenic risk is calculated for that setting by adding risks across carcinogens. Carcinogenic risks may be summed together given the assumption of a non-threshold linear dose-response curve. Because this assessment addressed only one noncarcinogen, nitrate/nitrites, the noncarcinogenic hazard for this contaminant is equal to the total noncarcinogenic hazard.

Once the total carcinogenic risk and noncarcinogenic hazards have been calculated for each environmental setting, a national risk and hazard estimate is generated by weighting the individual setting risks based upon their national frequency of occurrence. As described in Appendix 4.1.3, the frequency of occurrence of lagoons in each setting was based upon a characterization of the United States into hydrogeologic regions using the DRASTIC methodology. Figure 4.1-4 in Appendix 4.1.3 displays the numbers of lagoons found in each of the DRASTIC regions; Table 4.1-14 (Appendix 4.1.4) presents the number of lagoons corresponding to each of the nine environmental settings modelled.

Figure 5-1
National Aggregate Carcinogenic Risks



5.2 DISCUSSION OF QUANTITATIVE MODELLING RESULTS

5.2.1 Weighted National MEI Risks

Weighted national MEI risks were calculated using both median and maximum lagoon effluent concentrations as estimates of the leachate concentration. Because of several conservative assumptions described in Section 5.4.2, these risk estimates are likely to overestimate actual risks. The importance of leachate concentration with respect to risk is evident. The national distribution of total carcinogenic risks associated with median lagoon effluent concentrations ranged from 1.6×10^{-5} to 4.0×10^{-5}, while risks associated with the maximum concentrations ranged from 7.0×10^{-4} to 1.8×10^{-3}. Figure 5-1 shows cancer risks associated with median and maximum well concentrations versus cumulative probability of occurrence. The steep rise in the cumulative probability curves in Figure 5-1 indicates that there is little variation in risks nationally from lagoons (notwithstanding estimates of leachate concentration). Each point on the curve represents the probability that a facility will result in risks to the nearest exposed individual at or below the level on the X-axis. A risk of 4.0×10^{-5} means four persons in 100,000 will develop adverse health effects, in this case cancer, from this exposure. Noncarcinogenic hazard, caused by nitrate/nitrites, was negligible nationally, with ground-water concentrations never exceeding one ten-thousandth of the level associated with the toxic health effect methemoglobinemia (100 ug/l).

Each EPACMS run included approximately 500 iterations in which distance to wells, environmental parameters, lagoon size, and other variables (See Appendix 4.4) were varied independently by the Monte Carlo simulator. Appendix 5.2 displays the ninetieth percentile risks associated with all seven constituents in each of the nine hydrogeologic settings for both median and maximum effluent concentrations. (The ninetieth percentile risk is the risk associated with a nine in ten chance of occurrence.) The constituents dominating the weighted carcinogenic risks varied between the median and maximum effluent concentration model runs were due primarily to differences in the relative magnitude of leachate concentrations. The median concentration risks were dominated by two pollutants found only in the domestic/industrial lagoons, hexachlorobenzene and benzene, with risks ranging from 3.0×10^{-7} to 4.5×10^{-5}. The maximum leachate concentration risks were dominated by three constituents found primarily in domestic/industrial lagoons: hexachlorobenzene, 2,4-dinitrotoluene, and chloroform, with individual risks ranging between 2.9×10^{-5} and 1.5×10^{-3}.

The other potential pollutants of concern for carcinogenic risk, arsenic and tetrachloroethylene, posed relatively insignificant risks compared to the dominant chemicals.

5.2.2 Comparison of Risks from Domestic and Domestic/Industrial Lagoons

The lagoon data survey did not provide sufficiently representative data to allow health risks associated with domestic and domestic/industrial lagoons to be quantified separately. Although the data characterizing the lagoons cannot be considered statistically representative of lagoons nationwide, a number of observations can be made about the different risks that may be expected from these two types of lagoons; in general, risks from domestic lagoons are significantly less than those from domestic/industrial lagoons.

Because the pollutant concentrations in the domestic/industrial lagoons were significantly higher than those detected in the domestic lagoons, the maximum concentration risk results correspond primarily to the risks associated with domestic/industrial lagoons. The pollutants dominating the maximum concentration estimates (hexachlorobenzene, 2,4-dinitrotoluene, and chloroform) were observed solely in the domestic/industrial lagoons and were not detected in the domestic lagoons (with the exception that chloroform was detected in quantifiable concentrations once in the domestic lagoons; nonquantifiable trace values were detected in 3 other lagoons). All of the maximum effluent concentrations modelled represent levels detected in the domestic/industrial lagoons. In addition, the median concentration risks were also dominated by two pollutants not detected in the domestic lagoons: hexachlorobenzene and benzene.

The risks attributable to domestic lagoons correspond to the risks associated with the four pollutants detected in them: arsenic, chloroform, nitrate/nitrite, and tetrachloroethylene. Arsenic was detected in two of the nine lagoons at equal concentrations of 11 mg/l, which is about eight times lower than the maximum level modelled. Therefore, the risks from arsenic in domestic lagoons are likely to be in the range of 1 x 10^{-6}. Chloroform was quantified in one of the nine domestic lagoons, at a concentration of 2.3 mg/l, more than 10 times lower than the maximum level detected in the domestic/industrial lagoons. The chloroform risks from domestic lagoons, therefore, probably do not exceed 2 x 10^{-5}. The nitrate/nitrite levels in the ground water were extremely low and and do not represent a health threat. Finally, tetrachloroethylene was detected in two of the nine domestic lagoons at concentrations less than 1.5 mg/l, between one and two orders of magnitude less than the levels detected in the domestic/industrial lagoons. The risks from tetrachloroethylene at domestic lagoons are therefore unlikely to exceed 5 x 10^{-6} based upon the lagoon survey data. Table 5-1 summarizes these estimates of variation between domestic and domestic/industrial lagoons.

5.2.3 Distribution of Risks Across Hydrogeologic Settings

EPACMS provides distributions of risk estimates corresponding to the Monte Carlo input values for each of nine separate hydrogeologic settings. The risk estimates within each setting varied by less than one order of magnitude between the 10th and 100th percentile risks. In addition, the risk estimates varied little across environmental settings. The 10th percentile maximum aggregate carcinogenic risks varied from 1 x 10^{-3} to 6.3 x 10^{-4}, while the 100th percentile maximum aggregate cancer risks varied from 1.8 x 10^{-3} to 2.1 x 10^{-3} across the nine hydrogeologic settings. The lack of variation in setting risks can be attributed to interactions between the dominant hydrogeologic parameters, such as hydraulic conductivity, depth of the saturated zone, and the slope of the groundwater table. Because most lagoons are sited near rivers within flood-plain areas, the hydrogeologic conditions are quite similar across the country.

5.3 QUALITATIVE DISCUSSION OF POPULATION RISKS

The total risk to exposed populations depends upon the location of all residences and public water supply wells (rather than the closest well) within the vicinity of municipal wastewater treatment lagoons. The mapping survey of 220 lagoons produced a distribution of potentially exposed populations within 2000 meters of wastewater treatment lagoons, and found that an average of 391 persons depend upon ground water within 2000 meters of wastewater treatment lagoons nationally (Appendix 5.3, Table 5.3-1).

The magnitude of risks to these exposed individuals depends upon their distance from the lagoon. The mapping survey found that less than 8% of the potentially exposed populations live within 500 meters of a lagoon; no public water supply wells were observed within 130 meters of a lagoon. Because the distribution of total exposed populations at lagoons is weighted to greater distances and contaminant concentrations decrease with distance, the magnitude of population risks attributable to municipal lagoons is likely to be relatively low. The risks to populations residing near domestic/industrial lagoons are likely to be much higher than those affecting populations near lagoons receiving only domestic wastes.

TABLE 5-1

MEI CANCER RISKS (GROUND WATER) FROM MUNICIPAL LAGOONS

	MEI Risk Associated With Leachate Concentration		
Lagoon Type	Median	Maximum	Risk-Dominating Constituents[a]
All Lagoons	1.6×10^{-5} to 4.0×10^{-5}	7.0×10^{-4} to 1.8×10^{-3}	Hexachlorobenzene, benzene, chloroform, 2,4-dinitrotoluene
Domestic only	Negligible	1.0×10^{-6} to 2.0×10^{-5}	Chloroform, arsenic, tetrachloroethylene

[a] Arsenic and tetrachloroethylene were found in quantifiable concentrations in two of the nine domestic lagoons sampled and chloroform in one of the nine lagoons.

While the geographic areas used to select a random sample of lagoons for the mapping survey were not selected statistically, the results are likely to be quite representative of national trends. Generally, wastewater treatment lagoons are located downstream of towns within close proximity to the point of effluent discharge into the river. This does not allow residences to be located between the lagoon and the receiving stream, which often intercepts the potentially contaminated ground-water flow, thus preventing further subsurface migration of contaminants. Additionally, people generally do not choose housing within a close proximity to wastewater treatment facilities due to potentially objectionable odors. These factors support the findings of the survey, which indicates that approximately 25% of all wastewater treatment lagoons may have no exposed populations within 2000 meters.

5.4 FINDINGS AND CONCLUSIONS

5.4.1 Magnitude and Distribution of Risks

This analysis has shown that the national risks associated with ground-water contamination from municipal waste treatment lagoons are generally low and within an acceptable risk range (10^{-4} to 10^{-7}). However, risks may exceed this range for certain lagoons receiving both domestic and industrial wastes in certain hydrogeological settings in the country.

The risks to populations exposed to contaminated ground water from municipal wastewater treatment lagoons will depend principally on the types of wastes received by the facility. The analysis indicates that facility location has only a slight impact on risk levels. Based upon the lagoon sampling survey, lagoons receiving only domestic wastes do not appear to pose unacceptable risks to populations, with maximum carcinogenic risks ranging from approximately 2×10^{-5} to 5×10^{-6}. These risks correspond to three carcinogens which were detected in only a few of the nine domestic lagoons sampled, and therefore may overstate the actual risks from domestic lagoons. The most common pollutant identified in domestic lagoons, nitrate/nitrite, was shown to pose little or no threat to human health based upon the modelling results.

Some lagoons receiving mixtures of domestic and industrial wastes may pose more substantial risks to human health. Median carcinogenic risks for these lagoons are approximately 10^{-5}, with maximum risks ranging as high as 1.9×10^{-3}, due primarily to hexachlorobenzene and 2,4-dinitrotoluene. However, these maximum risks may be rare occurrences. Because one of the primary factors affecting risk is the concentration of pollutants in the leachate, the applicability of these risk estimates to the nation is limited by the representativeness of the sample data. Lagoons that do not receive the riskdominating pollutants may pose substantially lower risks to human health.

5.4.2 Modelling Assumptions and Limitations

Several limitations and assumptions apply to the quantitative modelling results described here. These include limitations to the applicability of the model and assumptions regarding model inputs and data described previously in Chapter 2. In general, these assumptions will tend to overstate the actual risks.

Although the health risks modelled here represent the best available information, only a small number of municipal lagoons were sampled (0.2% of domestic lagoons and 3% of domestic/industrial lagoons). Furthermore, assuming leachate concentrations to be equal to effluent concentrations may overstate risks, as physical processes that may reduce pollutant concentrations in the leachate, such as adsorption and biodegradation in the sludge layer, were not considered.

Because of the low frequency of detection for many of the pollutants of concern, the model employed detection limits as leachate concentrations when the median value represented a non-detect. This may overstate the median risk results, as the detection limit represents the upper-bound concentration in these cases. Similarly, the maximum concentration values often represented outlying data points, and may not be representative of most lagoons. Therefore, the maximum lagoon risk estimates may also overstate risks.

EPACMS assumes steady-state conditions in estimating ground-water concentrations of contaminants at wells. Steady-state models do not account for differences in breakthrough time at downgradient ground-water wells associated with contaminants with different mobilities. (EPACMS does account for the additional opportunity for attenuation of degradable contaminants in the saturated zone associated with the longer travel times of low mobility contaminants). Because it may take longer for lower mobility contaminants, such as 2,4-dinitrotoluene, to reach a point of exposure than faster contaminants, such as benzene, there may be no risk to existing populations from the a low-mobility contaminant for many years. Accordingly, the risks to existing populations may be overstated by these results.

United States Geological Survey (USGS) 7.5-minute series quadrangle maps were used to located residential and public wells in the vicinity of lagoons. Residences not served by a public water supply (as indicated in the FRDS data base) were assumed to have private water wells. This information is the best available for residences and ground-water usage, but the accuracy of the results depends upon the date of the USGS maps and the FRDS data base.

The exposure survey assumed that populations located downgradient of rivers large enough to intercept the ground-water flow would not be exposed to contaminated ground water. Identification of situations in which ground-water flow is likely to be intercepted by surface water depended upon professional judgment concerning the flowrate of the receiving stream and the likelihood that all of the local ground-water flow would discharge into the stream.

Chapter 6

ALTERNATIVES TO PREVENT AND CONTROL GROUND-WATER CONTAMINATION

6.1 INTRODUCTION

The results of the assessment presented in Chapters 4 and 5 overrepresent the potential ground-water contamination problem, due to the various conservative assumptions employed in the modelling approach. With this in mind, the following discussion of appropriate preventive and corrective technologies is directed primarily at those wastes, hydrogeologic settings, and lagoon designs that are most likely to present a potential for contamination of underlying ground water, with a resulting potential health risk to nearby populations. The installation, retrofitting, or decontamination of a lagoon should be specific to that particular lagoon and its wastes; measures which may be necessary for a lagoon receiving industrial wastes may not be required for a purely domestic lagoon.

Many of the measures discussed in this chapter can be implemented at several points during the useful life of a lagoon: (1) during design/construction of a new lagoon; (2) as part of retrofitting activities; or (3) as part of cleanup activities following discovery of contamination of soil, ground water or both. The types of preventive/corrective actions and their applicability to these three cases are presented in Table 6-1 and discussed in more detail in the following sections and Appendix 6.

In addition to the preventive/corrective measures discussed, States may also have guidelines and standards for design, construction, and operation of municipal lagoons. For example, the State of Wisconsin recently established ground-water quality standards applicable to all "facilities, practices and activities" which may affect ground-water quality and which are regulated under specific statutes by various State agencies (1). Under the new regulations, numerical standards were established for two sets of parameters (one set protecting public health and the other protecting public welfare), enforceable at various points adjacent to the pollutant source depending upon the type and concentration of the pollutant. Should these standards be exceeded, the Wisconsin Department of Natural Resources will assess the cause and significance of the exceedance and specify the appropriate response action, which may range from no action to site closure and treatment of contaminated ground water. Even if a facility complies with State seepage limits and other requirements, it is not excused from further regulatory action should the facility still leak. Facility operators should therefore be encouraged to consider exceeding the minimum State requirements.

Federal resources are also available to aid States in protecting public water supply wells through EPA's Wellhead Protection Program. As part of this program, EPA has established technical guidance to help States identify and delineate the areas around public wells needing protection through locally-established mechanisms such as zoning or land use restrictions. Additionally, federal grant money is available for program development in those States meeting grant eligibility requirements.

TABLE 6-1

TYPES OF PREVENTIVE/CORRECTIVE MEASURES

	New Lagoon	Retroffited Lagoon	Problem Lagoon[a]
Use proper siting criteria	x		
Install single or double liner (natural or synthetic material) as appropriate; choose compatible liner material	x	x	x[b]
Install leak detection/collection system as appropriate	x	x	x[b]
Practice construction QA/QC for new and retrofitted lagoons	x	x	x[b]
Implement or change O&M, inspection procedures	x	x	x[b]
Require industrial wastewater pretreatment to remove pollutants of concern prior to entering the lagoon	x	x	x[b]
Conduct ground-water monitoring	x	x	x
Retrofit to minimize potential for future contamination		x	x[b]
Control the source of contamination via containment, treatment, or removal of water, sludges and/or soils, including full or partial closure as appropriate			x
Contain and/or treat contaminant plume			x

[a] Lagoons with know contamination.
[b] This category may overlap with retrofitted lagoons in cases where contamination is minor.

6.2 NEW LAGOON

The design, installation and operation of a new municipal lagoon can be divided into four major components:

- Siting
- Design and material selection
- Construction
- Operations and maintenance

Although proper performance of the first three components listed above is usually (if not always) necessary to ensure the integrity of a lagoon system, it may not be sufficient. Even the best-designed lagoons may leak if appropriate quality assurance and control procedures are lacking during construction. The potential for lagoon leakage can be further increased if the necessary operations and maintenance (O&M) procedures are not performed. However, if care is taken to include all relevant site-specific considerations, lagoons can be designed and constructed so as to minimize the potential for leakage.

6.2.1 Lagoon Siting.

The siting of municipal lagoons must first take into account such practical considerations as:

- Site-specific parameters related to ground-water contamination including soils, hydrogeology and geology;

- Land availability and costs;

- Proximity of receiving streams;

- Proximity of existing and anticipated residential or other aesthetically sensitive areas;

- Proximity of water supply sources (surface water or ground water); and

- Proximity to existing and anticipated facilities (if the lagoon is part of a plant expansion).

6.2.1.1 Soils, Hydrogeology and Geology. Soils at the site must be tested to determine their suitability as subsurface material for the proposed lagoon design. Both the subgrade and impoundment structures such as dikes and berms require soils of appropriate strength, permeability, volume change, plasticity and compactability. Ideal soils will have low shrink/swell properties, low organic content, and minimal amounts of carbonate or other soluble materials. The availability of soils containing the required properties can be a major factor in determining the location of a surface impoundment. Should appropriate materials not be available locally, they must be transported to the site, usually a costly proposition. On the other hand, the presence of inappropriate or "problem" soils can limit or prohibit the installation of that lagoon at a particular site.

One of the most important considerations in siting a lagoon is the location of the water table and underlying aquifer(s). Depth to ground water and the historical seasonal changes in aquifer levels must be defined to allow sufficient distance between the saturated zone and the bottom of the lagoon. This minimum separation distance is often defined by State regulations; for example, the 1978 Recommended Standards for Sewage Works (2) require a minimum of 4 feet between the bottom of a lagoon and the maximum ground-water elevation. This criterion may not always be adequate, as seasonal and long-term fluctuations in water table elevation may not always be determined to that accuracy.

The underlying geologic conditions must be determined to ensure siting on a stable geologic foundation. Areas of karst geology or otherwise highly porous or fractured materials should be avoided, as well as areas of potential subsidence (e.g., collapsing soils, mined-out areas and sink holes) and geologically active areas (e.g., volcanism and recent faults). These conditions could cause slow-acting deformations resulting in liner breach or catastrophic failure as in the case of a fault zone or sink hole. Ideally, the impoundment should be sited in a stable area of massive clay strata or clayey soil with low permeability.

6.2.1.2 Topography, Surface Hydrology and Climate. These three factors, topography, surface hydrology and climate, are usually of lesser importance with respect to ground-water contamination than site soils and hydrogeology. However, they should still be taken into account when siting a municipal lagoon.

In choosing a lagoon site the local terrain must be such that the potential for a release caused by dike failure is minimized. Sites within the 100-year flood-plain or in areas of high relief are not recommended. Should a lagoon flood or overtop its dikes, pollutants would be released to unprotected (i.e., unlined) ground surfaces where they might infiltrate into the soil and ground water. (The most significant impact of such a release would, of course, be on local surface waters.) Consequently, the effects of climate must be considered. Regions of excessive rainfall and flooding, frost penetration and extreme temperature variations must be evaluated with care. Often, design and engineering techniques can accomodate climate-sensitive parameters.

6.2.1.3 Distance to ground or surface water supply wells or intakes

The distance between a lagoon and a drinking water well or surface water supply intake has a large impact on the human health risks associated with ground-water contamination. Ideally, lagoons should not be located near drinking water wells or surface water intakes.

6.2.2 Lagoon System Design

Lagoon design can be divided into two major components: (1) sizing; and (2) selection of an appropriate liner system. The sizing of a lagoon system is determined primarily by the type and degree of treatment necessary for the given wastewater. An additional consideration when sizing a lagoon is the effect of water column depth on the potential seepage rate (see Appendix 4.1.3).

In contrast, the selection of a liner system is determined by the level of protection required to prevent the lagoon's contents from entering the ground water at a specific site. It is related to lagoon operation only to the extent that treatment operations determine the nature of any contamination that may occur (i.e., the concentration and type of pollutants present in lagoon wastewater). Other site-specific factors such as location (i.e., depth) and use of ground water, proximity of withdrawal wells and soil type are also significant.

Liner material can be of three major types: (1) earthen, asphalt and cement liners ("admixed", or mixed in-place, materials); (2) synthetic and rubber liners; and (3) sealants (natural or chemical). The selection of a liner material is based on numerous factors that are site-specific (as discussed above) and liner-specific (e.g., chemical resistance, ease of installation and repair, costs, and availability).

6.2.2.1 Selection of a Liner System. Lagoon liner systems can be classified into two general categories:

- Single (i.e., monolayer) liner (Figures 6-1 and 6-2)
- Combination double (i.e., two-layer) liner, with a leak detection/collection system installed between the two liners (Figure 6-3).

The selection of a liner system for a municipal lagoon is based on the degree of protection desired (or required, in the case of State regulations). This decision must be based on several factors:

- The nature of the wastewater;
- Local hydrogeology, including the presence of naturally occurring low permeability strata at the site, depth to the water table, and the hydraulic conductivity of the outcropping or subcropping geologic unit;
- The use of underlying ground water and the proximity of any withdrawal wells;
- Expected lagoon life and closure requirements; and
- Federal, State or local regulations regarding seepage rates, liner materials, permeability, etc.

FIGURE 6-1

SCHEMATIC OF A COMPACTED SOIL SINGLE LINER SYSTEM FOR A LAGOON

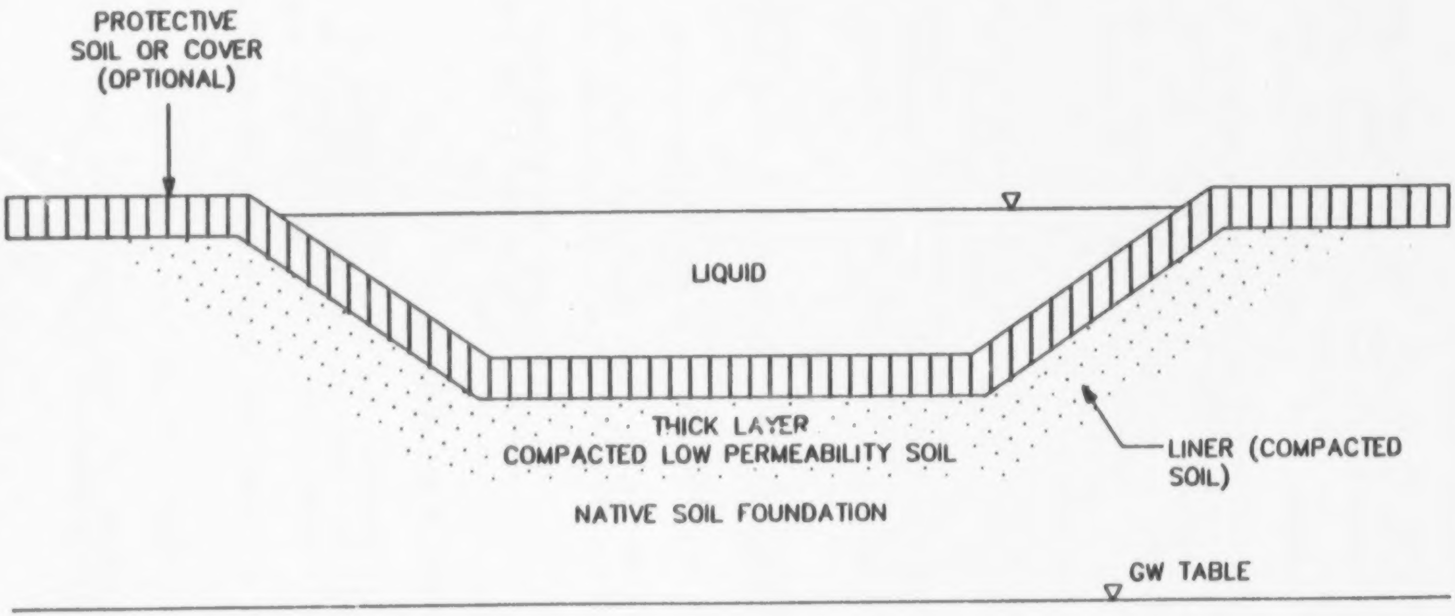


FIGURE 6-2

SCHEMATIC OF A FLEXIBLE MEMBRANE SINGLE LINER SYSTEM FOR A LAGOON

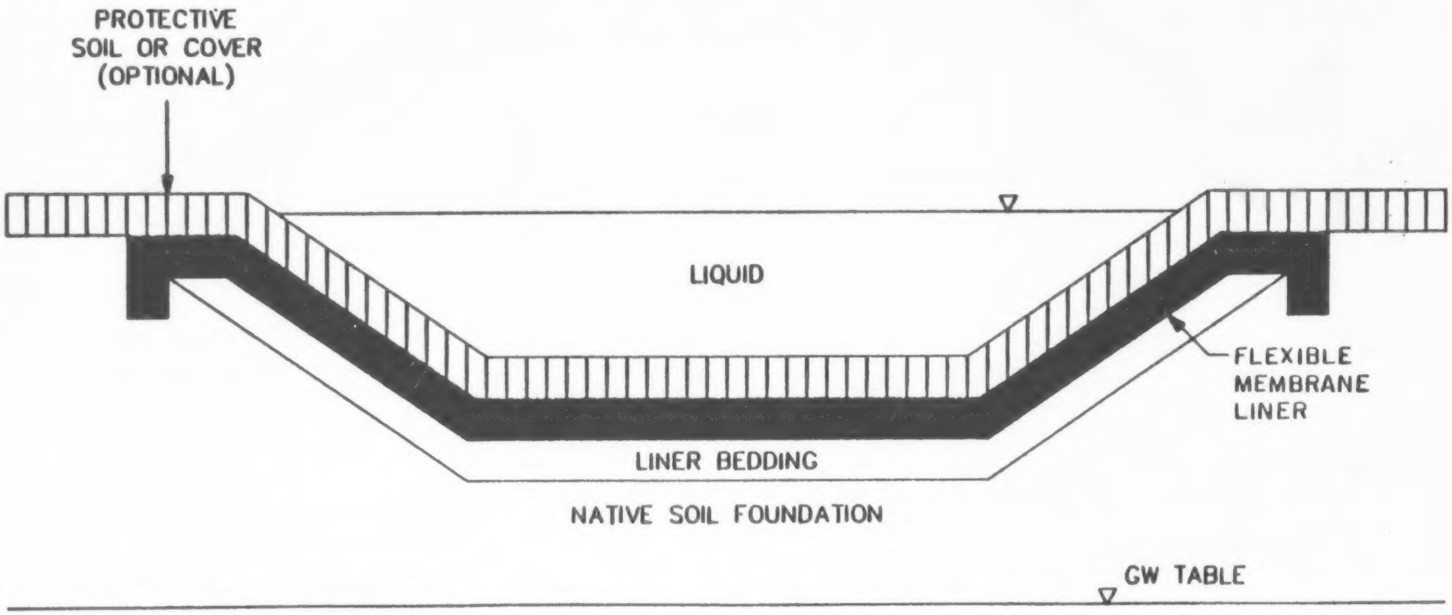
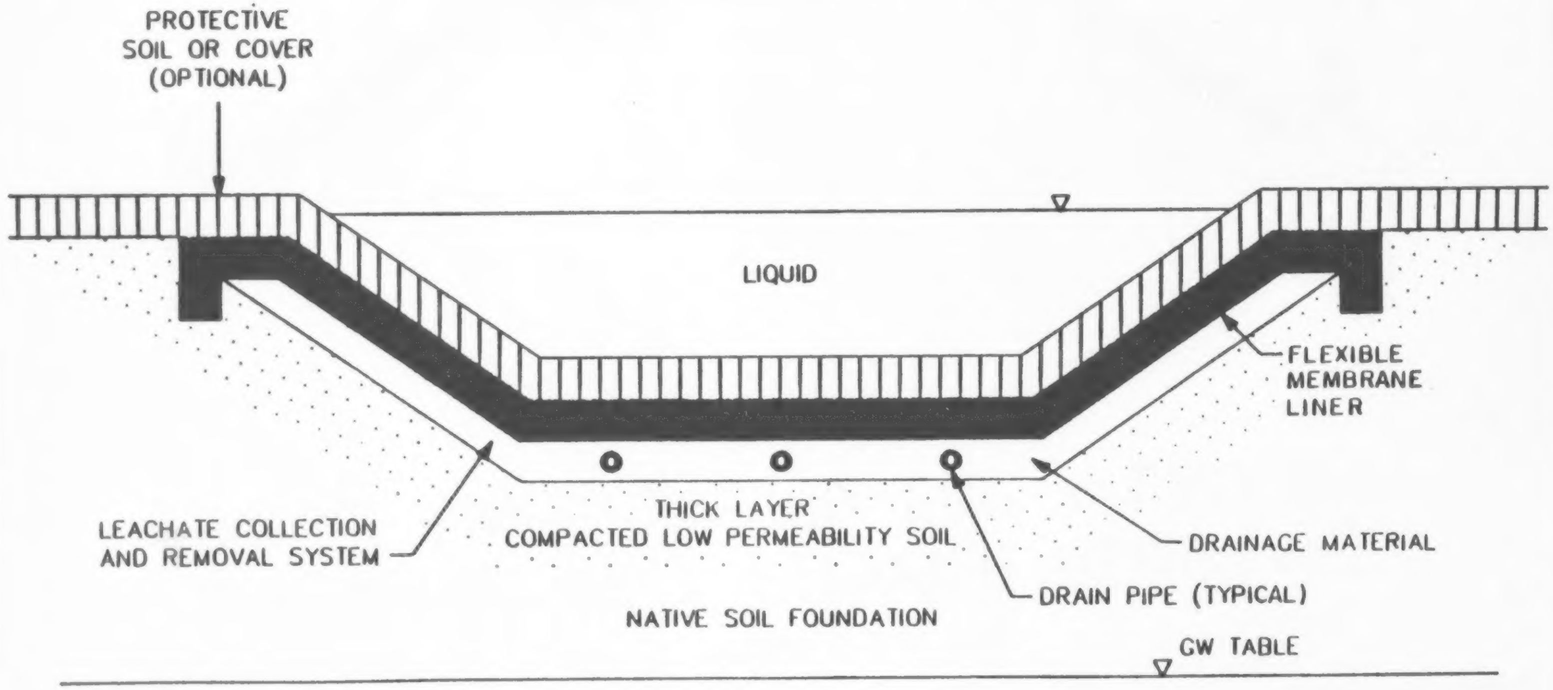


FIGURE 6-3

SCHEMATIC OF A FLEXIBLE MEMBRANE/ COMPACTED SOIL DOUBLE LINER SYSTEM FOR A LAGOON



The degree of protection provided for a given lagoon system must be decided on a site-specific basis. Most municipal lagoons currently in existence are constructed with a single liner, usually comprised of bentonite or low-permeability soil. In many cases, single liners (e.g., soil-bentonite) may be adequate; however, this may not necessarily be true for lagoons receiving large amounts of industrial wastes where individual compounds may contribute to liner degradation or present a significant health risk due to their inherent toxicity. In such cases, the installation of a double liner with a leak detection/collection system (Figure 6-3) may be warranted, especially if the lagoon is located in areas with susceptible hydrogeology and nearby water supply wells.

6.2.2.2 Liner Material Selection and Design Considerations. As with liner systems, the selection of a specific liner material is very dependent on waste characteristics and other site-specific parameters. Other factors to be considered include: (1) chemical compatibility of the liner and waste; (2) liner sensitivity to extreme temperatures and sunlight (ultraviolet radiation); (3) liner permeability under expected site conditions; (4) liner strength, life expectancy, ease of installation and repair; and (5) relative cost. The two major types of liners are earthen (e.g. clay), admixed (concrete and asphalt) and synthetic (e.g. rubber). Appendix 6.1 discusses the selection of liner materials and related design considerations.

6.2.3 Lagoon Construction

Lagoon construction can be viewed as a two-step process: (1) subgrade preparation; and (2) liner installation. Construction procedures are critical because inadequate quality control during construction can compromise or invalidate a superior design. Therefore, all phases of construction should be supervised to ensure that the design specifications are met, and, if necessary, revised after appropriate review when conditions at the site indicate the need for modification. A good quality control program will provide for sampling, inspection and monitoring of all phases of liner selection and installation. Documentation requirements for test results and all aspects of daily work should ensure adherence to engineering design while allowing for any necessary divergence from design specifications. For admixed liners, special attention must be given to characterizing the properties of the soil or other material to be used; while for synthetic liners, major areas of concern include subgrade preparation, seaming techniques, and sealing of penetrations through the liner.

Specific aspects of subgrade preparation and liner installation are discussed in Appendix 6.2 for synthetic and admixed liners. Installation of soil sealants, chemically absorbent liners, and spray-applied emulsions is not discussed as these methods do not provide an adequate hydraulic barrier when used alone.

6.2.4 Costs

The capital and O&M costs for a given municipal lagoon system depend on several site-specific factors, including:

- The facility's design capacity;
- The local cost of land;
- The need for a liner and, if so, the type; and
- The need for ground-water monitoring or other leak detection (and/or collection) systems.

6.2.4.1 Capital Costs. While costs vary among different systems operating under or in a wide variety of conditions, general cost information is available in the form of cost curves compiled by EPA (3). The cost curves compiled for aerated, facultative, and anaerobic lagoons are presented in Appendix 6.3.

As an example, if the facility to be constructed is designed to treat 0.1 mgd, the typical construction costs for a facultative lagoon system would vary from $181,000 in a warm climate to $419,000 in a cool climate. (June 1987 dollars; ENR Index of 4386.80). These costs include excavating, grading and other earthwork required for subgrade preparation, and service roads. The costs of liner material, installation and special subgrade preparation are excluded, as are the costs of land and pumping facilities. The resulting total capital costs, which include piping, electrical, instrumentation, site preparation, engineering, supervision and contingency costs, are $235,000 and $530,000 for warm and cool climates, respectively (June 1987 dollars). These total costs do not include auxiliary structures (e.g., offices, labs, etc.). A worksheet for these calculations is presented in Appendix 6.3 (Table 6.3-1).

If the lagoon is to be equipped with a liner, the capital costs for lagoon construction will increase significantly. For example, if the installed cost of a given synthetic liner is $8.00 per square yard, including additional subgrade preparation, and the area of the lagoon is approximately five acres (corresponding to a flow of 0.1 mgd, as derived in Chapter 3 and Appendix 3.3), then the total installed cost of the liner would be almost $200,000. Typical installed unit costs for selected synthetic, earthen and admixed liners are presented in Appendix 6.3 (Tables 6.3-2 and 6.3-3). Factors affecting the cost of liner installation include:

- Material costs;
- Suitability of local soils for use as subgrade, protective cover, or the liner itself;

- Location of site (i.e. transportation costs);
- Labor availability (often dependent on time of year);
- Economies of scale, if present; and
- Weather conditions (especially for seaming of synthetic liners)

6.2.4.2 O&M Costs. Cost curves for annual O&M costs are also included in Appendix 6.3. For a facultative lagoon treating 0.1 mgd, the corresponding June 1987 O&M cost is approximately $3,500 per year.

6.3 OPERATIONS AND MAINTENANCE

To ensure the integrity and proper performance of a lagoon system throughout its active life, if is necessary to implement an effective operations and maintenance (O&M) program. The major components of such a program include routine inspections, monitoring and preventive maintenance.

Routine inspection procedures begin with initial facility start-up and continue throughout final closure. The dike system should be inspected after major storm events or severe weather and the nature and extent of any problems should be documented, along with any follow-up maintenance required. The scheduling of routine inspections should be clearly outlined in the facility O&M manual.

If a leak is suspected or leak detection activities are required by regulatory authorities, there are several techniques available or under development for detecting seepage from wastewater lagoons. Some of these techniques are designed to identify leaks as they occur; others (e.g., ground-water monitoring) detect leaks only after they have occurred. The need for and selection of a particular leak detection method is usually determined on a site-specific basis. One reliable method of discovering a major leak is that of liquid mass balance; however, accurate measurements of inflow, outflow, rainfall and evaporation must be kept. Leachate collection systems can be a valuable tool in detecting the migration of wastes past the liner. Lysimeters, which sample the unsaturated zone beneath the impoundment, have also been successfully used to detect seepage. Several new techniques are emerging to measure liner integrity and detect leakage, including ground deformation monitoring, acoustic emission monitoring, and several types of geophysical techniques. Innovative sensing systems are being designed to improve leak detection at planned impoundment sites (4, 5, 6, 7 and 8).

If ground-water contamination is suspected to have occurred, a ground-water monitoring program can be instituted to measure any effect(s) the lagoon may have on the underlying aquifer. Should this be necessary, care must be taken to locate the monitoring wells so that at least one well is upgradient and several are downgradient, spaced at appropriate intervals to intercept the flow of ground water. Leachate contamination from waste impoundments has been shown to move as a distinct plume within the ground-water flow. Placement of monitoring wells to sample several sections of the aquifer is usually necessary to identify and locate a contaminant plume. Other innovative techniques that have been used to locate contaminant plumes include high frequency pulse, electromagnetics, resistivity and seismic techniques.

The cost of ground-water monitoring can vary greatly, depending upon several factors:

- Number of wells;
- Depth to ground water;
- Location of bedrock: If bedrock is shallow, equipment such as air, specialized rotary, or rock coring drills will be necessary;
- Type of soil: Very sandy soil may cause cave-ins or "heaving sands," where the sand rises in the hollow auger during drilling. If this occurs, it may be necessary to employ mud rotary or other specialized drilling techniques; and
- Degree of contamination: If severe ground water or soil contamination is encountered, it will be necessary to implement a higher level of personal protection (e.g., Tyvek suits, respirators, etc.). This is not likely to be necessary at municipal lagoon facilities.

Costs for a typical monitoring well system are presented in Appendix 6.3 (Table 6.3-4). These costs assume:

- Four monitoring wells (one upgradient and three downgradient) with 4-inch PVC pipe;
- A well depth of 40 feet (assumes a water table at 20-25 feet below ground surface);
- Silty soil (allows use of a hollow stem auger);
- Quarterly sampling of each well; and
- Analysis of well samples for priority pollutants; a fifth sample (field blank or wash blank) is included for QA/QC purposes.

Based on the above assumptions, the total installation costs (including supervision) for a four-well system are $15,000 (±20%). The total yearly sampling and analysis costs are estimated at $43,000 based on quarterly sampling (June 1987 dollars).

If occasional or periodic increases in particular compounds in pond influent are expected (e.g., seasonal industrial discharges), it may be advisable to monitor pond influent on a regular basis to detect the presence of these compounds. If it is determined that these compounds are present at levels high enough to impair the lagoon system, either by inhibition of biological action or by attacking the integrity of the liner, it may be necessary to require dischargers to pretreat their wastewater prior to release to the lagoon system.

Routine inspection and monitoring will document any required maintenance and repair due to weathering, animal or human intruders, or structural failures. Routine preventive maintenance will also keep spillways clear of debris, maintain embankment and dike slope vegetation and minimize erosion, and ensure scheduled fence repair and machinery upkeep.

All operations and maintenance procedures should be prescribed in a manual and distributed to appropriate employees. Written records should be kept of all O&M activities.

6.4 WASTEWATER PRETREATMENT

Certain compounds, when present in sufficiently high concentrations, can often have deleterious effects on both lagoon performance and integrity and can contaminate groundwater if seepage occurs. Lagoon performance can be adversely affected by compounds that: (1) inhibit oxygen transfer (e.g., surfactants); (2) inhibit nutrient uptake (e.g., heavy metals); or (3) limit cell metabolism (e.g., cyanide). These or other waste constituents can also compromise the integrity of a liner; for example, some synthetic liners are not resistant to hydrocarbon solvents and petroleum oils (see Appendix 6.1, Table 6.1-1). While it may not be likely that these compounds will be present in municipal lagoons in concentrations high enough to cause liner degradation, laboratory and field performance tests are advisable to confirm the compatibility of the liner material with the expected waste (4, 9, 10, 11, 12, 13 and 14). This is especially true of lagoons with the potential to receive a high proportion of industrial wastewater.

In general, pretreatment requirements for a given industry are specified for selected chemicals by the locality (e.g., city or sewer authority) based on EPA's Effluent Guidelines Limitations and/or local discharge requirements (whichever are more stringent). The industry is then free to choose a treatment process or processes to achieve pretreatment limitations. The particular type of treatment process applied is primarily a function of the type of waste (or industry), the concentration of pollutants in the waste, the desired level of treatment, and treatment cost.

Where several industrial plants discharge the same pollutant to a lagoon it may be necessary to restrict the pollutant loading from each plant and not just the pollutant concentration. A pollutant loading limitation is based on the appropriate local or categorical pretreatment standard and a dischange volume restriction. Pollutant loading limitations control the total amount of a pollutant which industrial plants can discharge. Such limitations insure that lagoons will not receive an excessive quantity of a pollutant.

Pretreatment requirements offer the distinct advantage of controlling industrial pollutants which may contaminate groundwater at their source and of posing the cost of groundwater pollution prevention on the industries that discharge the pollutants.

6.5 MODIFICATION OF AN EXISTING LAGOON

There are several circumstances under which it may be desirable to retrofit or otherwise modify operation of a municipal lagoon system; the most obvious circumstances are the discovery of a leak or release. Other relevant situations include changes in applicable regulations, changes in wastewater composition, or changes in operations philosophy.

If a lagoon system is found to have the potential for leaks, or an added degree of protection is desired (or required), any of several measures can be taken:

- The lagoon can be retrofitted with a lower permeability liner(s);
- The existing liner can be repaired;
- Pretreatment by dischargers can be required if it is determined that certain compounds present a significant risk to the potentially exposed population; and
- O&M and monitoring practices can be improved.

These options are discussed in the following sections.

6.5.1 Retrofitting

The most difficult design problem encountered in liner application is retrofitting of a liner in an existing lagoon. Effective design practices are essentially the same as those used in new systems, but additional care must be exercised in the evaluation of the existing structure and the required results. Lining materials must be selected so that compatibility between old and new sections is obtained. Sealing around existing columns and footings should also be considered (15).

6.5.1.1 Liner Replacement. Existing lagoons that are leaking, seeping excessively, or that have liners found to be in a deteriorated condition can be retrofitted with new liner systems if all supporting structures are sound. Liner replacement usually requires a shutdown period to drain and prepare the lagoon for the new liner.

Soil-bentonite and rigid liners with unacceptable cracks and increased permeability properties must be removed and disposed prior to replacement. If the degradation is due to waste-liner incompatibility, retrofitting with a synthetic liner may be desired. Where the lagoon bottom has deformed and caused cracks or other liner failure, grading and subsurface preparation will be required before liner replacement. A leachate detection/collection system may also be warranted prior to liner installation. If required by circumstances and/or regulatory agencies, contaminated subsoils should be treated or disposed off site prior to retrofit.

Synthetic liner replacement would similarly require draining the lagoon, removing the old liner, resurfacing the subgrade and installing the new liner. A double liner system of clay overlaid by a flexible membrane may be required to avoid a second failure. A leachate detection/collection system may also be desired. As above, it may be necessary to treat or dispose of contaminated subsoils.

6.5.1.2 Liner Repair. Of the admixed material liners, bentonite-soil liners can be repaired with the greatest ease and effectiveness. Bentonite-slurry additions to a filled pond can often repair small holes in a soil or bentonite-lined pond. Draining is required for repair of cement and asphalt mix liners which is not always effective. Placement of a soil layer over rigid materials may provide the desired low permeability layer. See References 2, 8 and 10 for further discussion.

Synthetic liners can be repaired by patching if the leakage is caused by a small hole and it can be located and reached without damaging the rest of the liner. A soil overlayer may be desired for added protection and may provide an hydraulic barrier sufficient to stop small leaks (2 and 8).

6.5.1.3 Measures to Assure Continuity of Operation During Retrofitting/Repair. Except as noted above, in most cases a lagoon (or portion thereof) must be removed from service during retrofitting/repair activities. If this shutdown is properly managed, the facility should be able to provide the level of treatment required by permit, as long as the remaining plant capacity is sufficient to handle expected flows. Continued successful operation depends primarily on the ability of plant personnel to define and take adequate measures to ensure that the design capacity of the remaining unit operations is not exceeded. Those remaining facilities must be able to handle their expected increased load during the repair period. Whenever possible, retrofitting and repair work should be conducted during periods of expected low flow to minimize the chance of capacity exceedance.

The overall success of any retrofit/repair activity depends on proper construction sequencing. All temporary diversion facilities should be fully operational prior to the initiation of work. The construction, installation and operation of these facilities should be explicitly included in the construction documents for the retrofit/repair work. Typical diversion facilities include temporary pipe or channel connections, diversion valves and gates and pipe plugs. In extreme cases, temporary lagoons may be constructed if required to maintain design capacity. Due to variations in the construction and operation of different facilities, the particular measures needed to ensure continued operation will be specific to each plant.

6.5.1.4 Costs. As for the construction of new lagoons, the costs for retrofitting an existing lagoon are very site-specific. Costs of liner repair are highly dependent on the size of the area requiring repair; unit costs for liner materials (as installed) are presented in Appendix 6.3 (Tables 6.3-2 and 6.3-3). Retrofitting an entire lagoon can require a variety of actions, ranging from simple placement of a liner with no additional excavation or subgrade preparation to removal and disposal of an old liner, recompaction and other subgrade preparation, installation of a new liner(s) and a leak detection/collection system, if necessary. Additional costs will be incurred through the need for temporary diversion facilities to ensure continuity of operation. These costs are site-specific and thus are not included in this discussion.

6.5.2 Improvement of O&M and Monitoring Practices

All existing O&M practices should be reviewed and any identified deficiencies should be corrected. Common deficiencies include:

- Infrequent and inadequate inspections;
- Inadequate preventive maintenance;
- Improperly sited monitoring wells;
- Improper Quality Assurance or Quality Control techniques used in sampling and analysis; and
- Inadequate training of personnel in O&M procedures and emergency/safety practices.

6.5.3 Pretreatment

Based on analyses of lagoon influent, it may be desirable to require pretreatment for specific waste dischargers to prevent damage (and subsequent need for modification, repairs, or both) to the lagoon system (see Appendix 6.4, Table 6.4-1).

6.6 LAGOON REMEDIATION

If contamination is discovered at a municipal lagoon facility and it is determined that the contaminants present pose a significant risk to human health and the environment, a site investigation must be performed and the need for remedial action assessed. Detailed guidance in the performance of both remedial investigations and feasibility studies has been prepared by USEPA for sites covered by the Comprehensive Environmental Response, Compensation and Liability Act, known as "Superfund" (15, 16 and 17). Although the guidance may not strictly apply to municipal lagoons, it provides a framework for structuring site investigation and selecting the best remedial alternative.

6.6.1 Site Investigation

The information to be obtained in a site investigation includes (to the extent needed to accurately assess conditions at the site):

- Detailed hydrogeology of the site, including the presence and location of low permeability strata or bedrock, ground-water flow gradient, flow velocity and the saturated thickness of the aquifer;
- Specific pollutants and their concentrations in wastewater, sediments, soils, and ground water (and their subsequent behavior in these media);
- Potential migration/exposure pathways (i.e., ingestion of contaminated ground water);
- The location and number of potential receptors (i.e., residents relying on local wells for drinking water); and
- The presence of nearby surface waters which may receive overland flow or exfiltrating ground water contaminated by the site.

The extent and level of detail of any site investigation will vary depending on the site and should be determined with the aid of appropriate regulatory authorities. For example, if the aquifer is not used and there are no potential receptors, less extensive sampling may be required than if water supply wells were located 500 feet downgradient. Regulatory authorities will use this information, along with available health effects data, to set target cleanup levels for the site.

6.6.2 Identification of Remedial Alternatives

Once the site investigation is complete, potentially applicable remedial technologies and alternatives should be identified for further assessment. Each alternative is subjected to a feasibility study, in which it is evaluated and compared with other alternatives on the basis of:

- Technical applicability;
- Impact on public health;

- Institutional considerations (e.g., regulatory requirements);
- Environmental impacts; and
- Costs.

Based on the feasibility study, one remedial alternative is recommended for implementation. This alternative may be comprised of several technologies, selected to address different aspects of a site (e.g., excavation and landfill of soil, on-site treatment of contaminated ground water and long-term ground-water monitoring). In some cases, remediation may be confined to source removal or containment, along with necessary restrictions on land and ground-water use.

General types of response alternatives that are potentially applicable to municipal lagoons are outlined in Appendix 6.5 (Table 6.5-1). Specific technologies that could be implemented as part of these response actions are listed in Appendix 6.5 (Table 6.5-2), along with their associated advantages and disadvantages. A similar analysis of processes suitable for the treatment of contaminated ground water is provided in Appendix 6.5 (Table 6.5-3). For detailed information on these technologies, the reader is referred to References 7, 17 and 18.

6.7 FINDINGS AND CONCLUSIONS

- For new lagoons, adherence to proper siting criteria, sound design and construction practices, industrial pretreatment and pollutant loading limitations , and finally a rigorous operations and maintenance program together can minimize the potential for groundwater contamination. Wherever seepage into an aquifer could occur, groundwater monitoring with properly sited upgradient and downgradient wells is essential for assessing actual contamination and, if necessary, determining the appropriate corrective action.

- A ground-water monitoring program with properly sited upgradient and downgradient wells is the basic prerequisite for defining measures to prevent ground-water contamination for new lagoons or reduce such contamination for existing lagoons.

- Available alternative measures that could be used to prevent ground-water contamination from new lagoons or control contamination from existing lagoons include one or more of the following:

  (1) Proper siting;
  (2) Pretreatment of industrial wastes;
  (3) Installation of properly designed synthetic or soil linings in new lagoons or retrofit and repair of such linings in existing lagoons;
  (4) Changes in inspection and maintenance procedures;
  (5) Leak repair or collection and treatment of leachate; and
  (6) Containment and treatment of the contaminant plume.

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